A CONCEPTUAL FRAMEWORK AND BEST PRACTICES FOR DESIGNING AND IMPROVING CONSTRUCTION SUPPLY CHAINS

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Dedication

Fernanda is my beautiful wife. Her love and support changed my life in many ways over the years we are together. She is right next to me in the good and bad days, all the time! This work is fully dedicated to her.

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The Ph.D. was a long journey. When I embarked on this ride, I was certain that it would be one of the greatest challenges of my life. Therefore, I would like to thank not only the organizations and people that helped me to complete the Ph.D., but also the ones who supported my wife and me, both in the UK and in Brazil.

I thank my mother and father for giving me the support, personal values, and unconditional love throughout my whole life. They will always be a source of inspiration to me.

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Declaration

I declare that the research contained in this thesis was solely carried out by me. This thesis has not been previously submitted to this or any other institution for the award of a degree or any other qualification.

The following publications, developed by the author of this thesis, share part of their contents with this research:

Souza, D. V. S., and Koskela, L. (2012). On improvement in construction supply chain management. In *Proceedings of the 20th Annual Conference of the International Group for Lean Construction*, 17 July to 22 July, San Diego, USA.

Souza, D. V. S., and Koskela, L. (2013). Practices for designing and improving construction supply chain management. In *Proceedings of the 21st Annual Conference of the International Group for Lean Construction*, 31 July to 2 August, Fortaleza, Brazil.

Souza, D. V. S., and Koskela, L. (2014). Interfaces, flows, and problems of construction supply chains - a cade study in Brazil. In *Proceedings of the 22nd Annual Conference of the International Group for Lean Construction*, 23 June to 27 June, Oslo, Norway.

List of Relevant Abbreviations

CDF	Collaborative Development Framework
CR	Constructive Research
CS	Case Study
CSCM	Construction Supply Chain Management
DSR	Design Science Research
EHS	Environmental, Health and Safety
ESI	Early Supplier Involvement
ETO	Engineer-to-Order
GDP	Gross Domestic Product
GSCF	Global Supply Chain Forum
IGLC	International Group for Lean Construction
KPI	Key Performance Indicator
LC	Learning Cycle
MP	Major Project
MPD	Major Projects Directorate
MST	Motivating Success Toolkit
NDD	Network Delivery and Development
OEM	Original Equipment Manufacturer
OPP	Order Penetration Point
PO	Purchase Order
RFP	Request for Proposal
SCA	Supply Chain Academy
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SME	Small and Medium Enterprise
UK	United Kingdom

Abstract

Construction supply chains are problematic to manage. Examples of recurring problems in construction supply chains are increased levels of non-conformances, delivery delays, and disruptions in supply, among others. Theoretical developments in the field of construction supply chain management are recent. Existing approaches in the literature are focused on managing project supply chains rather than adopting a long-term perspective from the enterprise level. A significant portion of the existing supply chain methods and frameworks was deliberately adapted from other sectors without hardly considering the context. The aim of this research is to develop a conceptual framework and a set of practices to tackle the problems of construction supply chains. Based on a Design Science Research approach, an initial solution was proposed. The solution is composed of a conceptual framework and a set of best practices. In order to refine the solution, three case studies were carried out in organizations in the heavy construction sector. Next, a focus group evaluated the solution and provided inputs for developing the final version. The conceptual framework contains the key parties (Enterprise, Projects, and Suppliers), the interfaces between such parties (Interface A, Interface B, and Interface C), and the flows (Information Flow, Physical Flow, and Capital Flow) realizing the interfaces in construction supply chains. The practices comprise Supply Chain Governance, Supply Chain Flexibility and Risk Management, Performance Management, Early Supply Chain Involvement, Category Management, Supplier Development, Prequalification of Suppliers, and Supply Chain Strategic Alignment. The framework can be used as a means to locate the problems of construction supply chains in specific interfaces and flows. By precisely locating the problems, the involvement of the right parties is facilitated. The best practices can be used as references to guide design and improvement initiatives in construction supply chains.

1 INTRODUCTION

The construction industry plays a major economic role. This sector employs a large number of direct workers, has a wide network of suppliers, and is directly responsible for a significant share of the Gross Domestic Product (GDP). However, companies in the construction industry are criticized due to their wasteful processes, frequent cost overruns in projects, fragmented supply chains, and high level of technological aversion (Dave 2013).

The construction industry in Brazil has contributed, over the last ten years, to 5.4% of GDP on average, although over the last three years this figure has risen to 5.7% (IBGE 2010). This industry consists of 80,000 registered firms, even though there are informal companies in the market. The entire value chain of the construction industry officially employs 6.8 million people (7.1% of Brazilian employment). The Brazilian government represents 40% of the demand in the construction industry, and such public investments are focused on infrastructure projects (IBGE 2010).

The UK construction industry is a major contributor to GDP as well: in 2011 it contributed 7.4% of the total UK GDP and this figure rises to 14% when the entire value chain of the construction industry is considered (LEK 2012). According to the opinion of specialists, such industry has been nominated as a growth driver for the UK economy over history (LEK 2012). The UK construction industry consists of 260,000 firms involved with site preparation, construction, improvement, repair, installations, and services, and they employ 2.2 million people (7.5% of UK employment). UK government investment plays a major role in the construction industry adding up to 40% of demand, and public investment has been historically focused on infrastructure, education, housing and health (LEK 2012).

Table 1 summarizes the key figures of the construction industry in the UK and Brazil. Both economies have a massive concentration of the construction market share in the top-10 construction companies. The top-10 contractors in revenue, both in Brazil and UK, have approximately 57% of the market-share of the top-50 companies in both countries (CBIC 2013; The Construction Index 2015). In this sense, major contractors play a key role in any attempt for turning around and reshaping the construction industry in these countries.

Table 1 – Overview on construction industry - Brazil *vs.* UK

Characteristics	Brazil	UK
Contribution to the GDP	5.7%	7.4%
Number of Registered Firms	80,000	260,000
Number of Workers	6.8 million	2.2 million
Percentage of Construction Workers out of Total Employment	7.1%	7.5%
Percentage of Demand from the Government	40%	40%

Considering the number of registered firms and workers in both countries, it is reasonable to say that construction has a powerful chain of interconnected companies. As one can identify in practice, the majority of such firms are Small and Medium Enterprises (SME), which are highly specialised in their activities. Such SMEs are suppliers of top construction companies, also named in this research as contractors, which are responsible for driving the entire chain as they capture and deliver the majority of major projects. However, in order to deliver projects properly (i.e. in terms of cost, time, and budget) such contractors must rely on suppliers of materials and specialised services. Considering that contractors have multiple and concurrent projects, which are supplied by a wide network of suppliers, a high level of complexity can be found in this environment. In this research, the task of managing such an environment is known as Construction Supply Chain Management (CSCM).

Globally, the construction industry has been changing over the last years, and presents an increasing complexity in its projects. Such complexity has derived from evolving customers' requirements and their implications in increased market competition. Commonly, construction companies have their projects segmented in four different types: housing, infrastructure, industrial, and commercial. The housing, industrial, and commercial projects have been developed aiming at customers from both public and private sector. Housing projects normally present increasing levels of intrinsic repeatability (i.e. a high-rise building has similar features across its different levels), and they tend to have similar characteristics between them. On the other hand, infrastructure projects have been usually related to the public sector. Infrastructure, industrial, and commercial projects have low levels of repeatability given that these projects require high levels of customization.

Infrastructure projects, both in Brazil and in the UK, are high-profile developments. Such projects are typically unique, they require specific suppliers, and they are geographically dispersed. Thus, companies building infrastructure projects face a complex task in managing their supply chains. Construction supply chains in the heavy infrastructure sector constitute the focus of analysis in this research.

1.1 Context of the Research

Gosling (2011) discussed the Engineer-to-Order (ETO) supply chain structure as an emerging field of study related to different industries, including construction. Construction supply chains have been related in research as analogous to engineer-to-order supply chains (Gosling *et al.* 2013a; Luhtala *et al.* 1994), and therefore they should be studied in a similar manner. In the same way, a construction company building infrastructure projects is highly related to the ETO supply chain structure, given the uniqueness of its projects.

According to Hicks *et al.* (2001), the study of ETO supply chains has been neglected when compared to other industry sectors. Such lack of investigation reduced the level of development in this field of study until recently. Emerging studies started to investigate supply chains in the ETO environment by looking at multiple organizations, dual demand management (part considering demand forecasts and part taking in consideration real demand), products highly customized, and converging logistics (Christensen *et al.* 2005; Gosling and Naim 2009; Gosling *et al.* 2012; Gunasekaran and Ngai 2005; Krajewski *et al.* 2005).

In the particular case of construction, Supply Chain Management (SCM) presents a set of intrinsic complex characteristics that deserves investigation, especially in terms of supply chain design and improvement. Such investigation is fostered by the existence of numerous interfaces in these supply chains, and by the need for increased general adaptation capabilities in supply chains (Lee 2004). The usual problems of CSCM occur at the interfaces between the different parties of the supply chain, namely the customer, sales department, engineering staff, manufacturing team, suppliers, sub-assembly and final assembly crews (Luhtala *et al.* 1994). The management of construction supply chains must rely on a structured approach for their design and improvement, given that their problems have endless implications. Such problems produce effects throughout the different tiers of the supply chain such as inventory fluctuations, waste, delays in project delivery, and cost overruns, among others.

CSCM can be analysed as analogous to production management as well (Luhtala *et al.* 1994; Vrijhoef and Koskela 2000). The task of managing construction supply chains can adopt the same principles of the production template: design, operation and control, and improvement (Souza and Koskela 2012). Moreover, supply chain management comprises the flow of materials, capital, and information (Luhtala *et al.* 1994), and such flow viewpoint constitutes also an analogous view of production management. However, it is noteworthy that the aforementioned flows come across different organizations.

The definition of a production strategy and a supply chain approach must be based on the characteristics of the product to be manufactured (Fisher 1997). Production volume, product customization, level of suppliers involvement, and production processes, among others, comprise the issues that must be evaluated in order to fully understand a production strategy (Choi and Linton 2011). In this sense, a 'one size fits all' viewpoint is not appropriate for managing supply chains in different sectors (Fisher 1997; Gosling 2011).

The ETO production strategy, adopted by construction companies in the infrastructure sector, has been characterized in the literature by its early Order Penetration Point (OPP) (Olhager 2003). The OPP related to the ETO production strategy is positioned at design, the earliest stage of production activities. According to this proposition, companies adopting the ETO production strategy deal with real demand, given that they do not plan their production schedule based on demand forecasts. The projects present unique characteristics and therefore they can be classified as ETO projects.

1.2 Research Problem

The research problem derives from the context described in section 1.1. The intrinsic characteristics of ETO construction companies reported by Hicks *et al.* (2000) and Hicks *et al.* (2001), such as highly customized projects, low levels of repeatability, early OPP, fixed position layout, planning based on real demand, the need for an early supplier involvement, all produce a variety of challenges in supply chain management. Such challenges are increased by high uncertainty levels, difficulties in coordination and integration of suppliers, and poor service level, among others (Luhtala *et al.* 1994). The combination of the aforementioned challenges constitutes a complex environment, given that these problems exist simultaneously. This condition can be attributed to the lack of efforts in supply chain design and improvement, which ultimately incur in day-to-day problems in operation and control. The problems arise at the interfaces between the construction company, its concurrent projects, and its multiple suppliers.

The majority of approaches for managing supply chains are known as process-oriented frameworks. Nevertheless, such frameworks were not conceived to address the specific characteristics of construction companies and their supply chains, which involve multiple, concurrent, and temporary projects. Such projects typically have different locations, require specific materials and components, demand specialty services, and present an intrinsic temporary nature. In this sense, a contextualized framework for addressing the problems of construction supply chains is needed. Hence, the lack of contextualized approaches for managing construction supply chains is the central motivation of this study.

The research problem to be addressed in this study is the lack of a contextualized, structured, and long-term oriented framework for designing and improving construction supply chains from the viewpoint of a construction company. The existing literature has limited developments in terms of the conceptualization of a construction supply chain. In addition, previous research has neglected the selection, evaluation, and consolidation of practices to support supply chain management in construction companies over time.

1.3 Aim and Research Questions

The aim of this research is to develop a conceptual framework and best practices to tackle the problems of construction supply chains.

The following research questions systematize the theoretical discussion of this investigation:

- How should construction supply chains be conceptualized in a framework?
- How can the problems of construction supply chains be located?
- How can practices be selected, assessed, cross-referenced, and consolidated in a framework?
- How can a set of practices be adopted by construction companies for tackling supply chain problems?

1.4 Structure of the Thesis

The dissertation comprises eight chapters and its structure is illustrated in Figure 1.

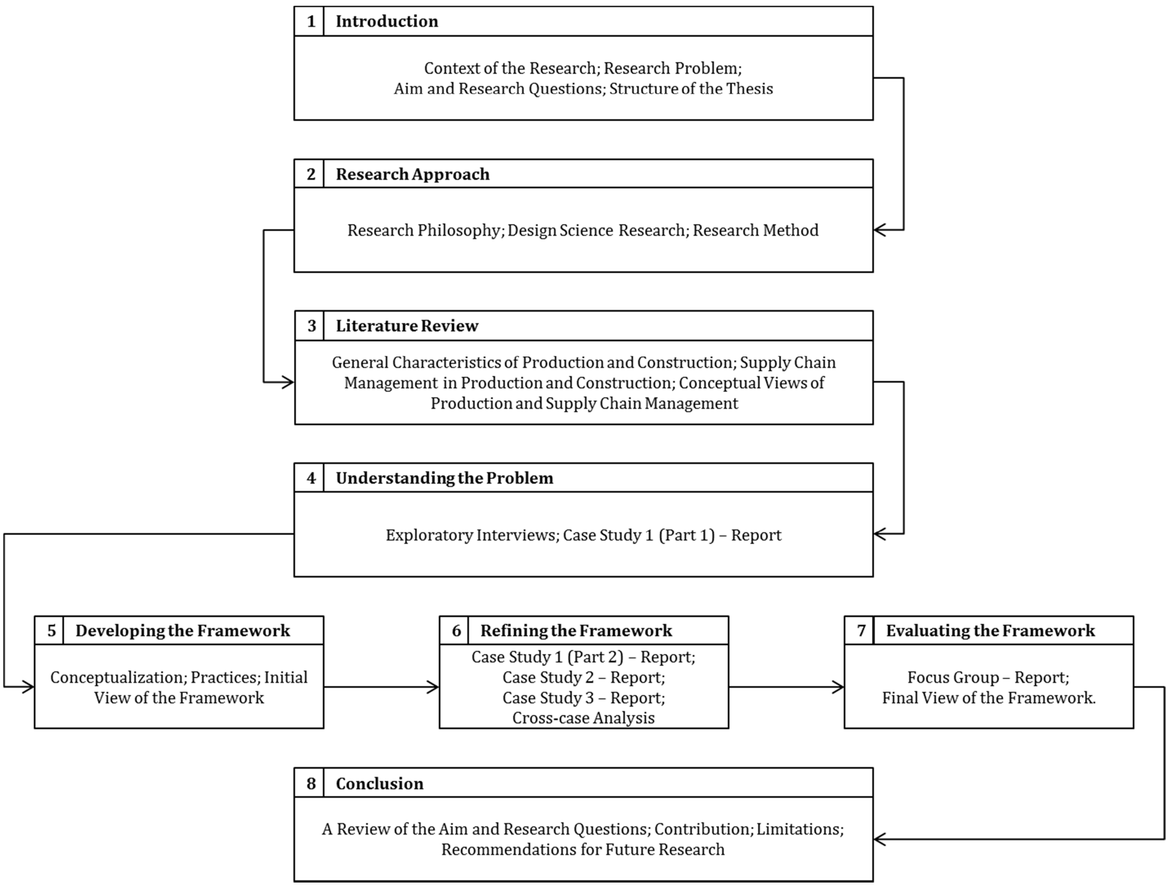


Figure 1 – Structure of the thesis

2 RESEARCH APPROACH

In this chapter, the research approach adopted in this thesis is delineated. First, an introduction regarding research philosophy is provided, in which basic beliefs and worldviews are presented. Next, the Design Science Research (DSR) methodology is summarized and discussed. This methodology is based on the development of solutions to solve practical problems. Finally, the research method devised by the author of this thesis is detailed. In the light of DSR, the method is divided in five sequential stages, namely Finding a Problem, Understanding the Problem, Developing the Solution, Refining the Solution, and Evaluating the Solution.

2.1 Research Philosophy

The underlying aspects of research are based on epistemological, axiological, ontological, and methodological paradigms. In relation to such paradigms, (Creswell 2013, p. 6) refers to the them as worldviews, meaning "a basic set of beliefs that guide action". Such philosophical worldviews form the assumptions for research development in managerial fields and they are discussed in the following section.

2.1.1 Basic Beliefs and the Worldviews

First, epistemology is commonly defined in the literature as the theory of knowledge embedded in the theoretical perspective and in the methodology (Crotty 1998). Second, ontology is commonly described in the literature as the study of being (Crotty 1998). Generally, ontological aspects are related to a single reality, to multiple realities, to the rejection of cultural relativism, and to the individuals' interpretation of reality (Mertens 2010). Third, axiology is defined as the nature of ethical behaviour (Mertens 2010). Finally, methodology is defined as an approach to systematic inquiry (Mertens 2010). Qualitative, quantitative, and mixed methods are the three typical research designs (Creswell 2013).

Creswell (2013) emphasized four worldviews or paradigms, namely Postpositivism, Transformative, Pragmatism, and Constructivism, which are presented in the topics below:

a) **Postpositivism:** this research paradigm does not comply with collaborative or participatory research (Javed 2008) and represents the traditional form of research (Creswell 2013).Such a worldview has a deterministic philosophy, and therefore supports the idea that causes determined effects (Creswell 2013). In addition, (Sexton 2000) highlighted that positivist studies endeavour to test theory in order to have a better understanding of the phenomena. Postpositivism, also called Positivism (Creswell 2013), has been closely related to the Quantitative Research design. In addition, Positivism is based on primarily deductive logic, on the axiology that values can be controlled, and on the ontology of transcendental realism (Javed 2008).
b) **Transformative:** this paradigm tangles with politics and a political change agenda in order to oppose social oppression at whatever levels it occurs (Creswell 2013; Mertens 2010). The research agenda aims at a major reform that may change the life of participants, the institutions in which they work, and the researcher's life (Creswell 2013). The aim of Transformative researchers is to develop a joint effort to promote social transformation (Mertens 2010). The Transformative paradigm presents respect for cultural norms, rejects cultural relativism, promotes an interactive link between researcher and participants, and usually involves both qualitative and quantitative mix methods (Mertens 2010).
c) **Pragmatism:** the focus of this paradigm is not methods: the emphasis is on the research problem and researchers use all approaches available to address the problem (Creswell 2013). Javed (2008) stated that the pragmatic approach is able to separate from the structures of social science and propose the adoption of qualitative and quantitative designs. Thus, the pragmatic paradigm provides an underlying framework for mixed methods research (Mertens 2010). Pragmatic research is underpinned by the gaining of knowledge in pursuit of desired ends, asserts that there is a single reality, and relationships within the study are determined by the focus of the researcher (Mertens 2010).

d) **Constructivism:** Flick (2013) highlights that there are different lines under the label of Constructivism, but all of them have a similar characteristic: such programs examine the relationship to reality by dealing with constructive processes. In addition, Flick (2013) highlighted that Constructivism reflects the reality as a social product of the different actors, interactions, and institutions. Creswell (2013) stated that the Constructivist approach leads the researcher to look for the complexity of the phenomena, and how the participants' views can be related to the situation studied. In this context, researchers should conduct an open discussion in order to construct the meaning of the situation and listen carefully to what participants say or do (Creswell 2013). Flick (2013) states that knowledge is constructed via social interchange and that researchers are part of the social construction. Nevertheless, the interpretation of the context in which the participants are is influenced by the background of the researchers in order to develop a theory or pattern of meaning (Creswell 2013). Crotty (1998) stated that constructivism in epistemology is very compatible with realism in ontology. Mertens (2010) states that the Constructivist approach presents a balanced representation of views, a set of socially constructed realities, and a positive link between the researcher and participants.

Research in construction supply chain management involves multiple actors from diverse companies and processes. Typically, the practical problems concerning supply chain management are complex and require in-depth investigation. In addition, solutions for practical problems should be developed and tested, so that they can be iteratively improved, retested, and evaluated. The research views described above do not fit properly in such iterative development, testing, and evaluation of solutions to practical problems. Thus, another research approach becomes necessary.

According to Voordijk (2009), most of scientific research in construction is focused on explaining and predicting phenomena relevant to design, production, and operation. However, this author discusses that the outputs of research developments in construction are solution concepts (i.e. technological laws, functional rules, and socio-technical understanding) and design rules. Construction as a design science is interested in socio-technical and usage contexts (Voordijk 2009), which can be associated with the built environment and also be extended to construction supply chains.

2.2 Design Science Research

Research has been first motivated by the need for solving managerial problems through the development of models, diagrams, and plans, among others (Kasanen *et al.* 1993). Nevertheless, a solution considered technically adequate will not necessarily work in practice (Kasanen *et al.* 1993), given that it is not easy to predict the functionality of a solution prior to its application.

The proposition of design sciences is mostly related to the field of engineering, medical sciences, and modern psychotherapy (van Aken 2004). DSR aims at designing artefacts that solve construction problems (mostly related with engineering) or solve improvement problems (related with medical sciences) (van Aken 2004).

The procedures adopted by DSR differ from the traditional approaches for research, and they are illustrated in Figure 2. Originally, the DSR framework comprises four elements for problem solving: practical relevance of the problem, theory connection, practical functioning of the solution, and theoretical contribution (Kasanen *et al.* 1993).

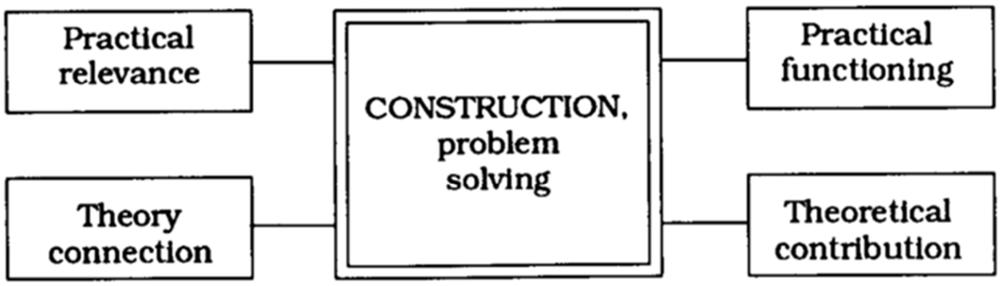


Figure 2 – Constructive Research Approach (Kasanen *et al.* 1993)

In order to perform problem solving, the DSR approach has been divided into steps in its original proposition (Kasanen *et al.* 1993):

- Find a practically relevant problem which also has research potential;
- Obtain a general and comprehensive understanding of the topic;
- Innovate, i.e., construct a solution idea;
- Demonstrate that the solution works;
- Show the theoretical connections and the research contribution of the solution concept;
- Examine the scope of applicability of the solution.

In addition, there are other researchers proposing different views about how the DSR framework should be structured. These propositions have not necessarily followed the same routine proposed by Kasanen *et al.* (1993), as one can identify in March and Smith (1995) and Lukka (2003).

On the one hand, March and Smith (1995) proposed a distinction between research activities (build, evaluate, theorize, and justify) and research outputs (constructs, models, methods, and instantiations). Constructs are a "conceptualization used to describe problems within the domain and to specify their solutions" according to March and Smith (1995, p. 256). A model is composed of a set of schemes that represents relationships among constructs, and a method is a set of steps (also referred to as an algorithm to perform a task) (March and Smith 1995). Finally, "instantiation is the realization of an artefact in its environment" according to March and Smith (1995, p. 258). The stage in which the understanding of the problem is developed by the researcher might lead to the creation of an artificial phenomena, also referred to as an artefact (Holmström *et al.* 2009). March and Smith (1995) stated that DSR aims to create things that serve human purposes, and are submitted to an evaluation that checks whether they work or not.

On the other hand, Lukka (2003) presented and discussed the DSR approach comprising the following steps:

- Find a practically relevant problem, which also has potential for theoretical contribution;
- Examine the potential for long-term research co-operation with the target organisation(s);
- Obtain deep understanding of the topic area both practically and theoretically;
- Innovate a solution idea and develop a problem solving construction, which also has potential for theoretical contribution;
- Implement the solution and test how it works;
- Ponder the scope of applicability of the solution;
- Identify and analyse the theoretical contribution.

Although the three above-mentioned publications (Kasanen *et al.* 1993; March and Smith 1995; Lukka 2003) discussing DSR have different terminologies and number of steps, all of them converge to a common point: DSR is a research method focused on solving real problems. Such common views have been also addressed by Holmström *et al.* (2009), positioning DSR as the basis of problem solving research. The creation of the artefacts contributes to solving a practical problem, which is the focus of DSR, but ultimately explains theoretically the phenomena itself (Holmström *et al.* 2009).

Equally important is the non-linear nature of research, and its implications in DSR. The process in which the artefact is reviewed and refined has different iterations (van Aken 2004; Holmström *et al.* 2009). Holmström *et al.* (2009) qualify the initial solution as rudimentary, and therefore the artefact must be developed throughout different learning cycles. According to van Aken (2004), problem solving is based on a reflective cycle, in which a case is chosen, planned, and interventions are implemented. Afterwards, a reflection upon the results is necessary in order to produce knowledge, which is tested and refined to serve as an input for the next cycle. According to van Aken (2004), there are two types of multiple-case studies: developing and extracting. In the developing multiple case-study the artefact is developed and tested by the researcher in the field (van Aken 2004). On the other hand, the extracting multiple case study focuses on the artefacts that already exist, which relates such studies as a 'kind of best-practice research' (van Aken 2004). Both extracting and developing types of multiple-case studies are supported by reflective cycles. Such cycles form the basis for developing knowledge to be tested and refined in further cases (van Aken 2004), which means the researcher should reflect upon the findings of each case study, and try and incorporate the lessons previously learned into the artefact. A refined artefact will be then ready to be tested in a new case study, which will also provide means for its improvement. According to van Aken (2004), based on the reflective cycles one can understand in what way the artefact should be improved.

The DSR approach forms the methodological underpinning of the present study. Both developing and extracting strategies are used for conducting and analysing multiple case studies. Reflective cycles, referred to in this research as learning cycles, are also developed in pre-defined stages of the research approach. It should be highlighted that the use of DSR as a research approach is recent in the field of construction management. However, a number of published PhD dissertations have adopted design science research, including the following but not limited to them: Rocha (2011), Rooke (2012), Dave (2013), and Sapountzis (2013).

2.3 Research Method

Empirical data was collected in several ways in this research: interviews, meetings, and documents, among others. The author of this thesis submitted the required documentation to obtain Ethical Approval in September 2012. All data collected was archived physically or electronically, and data is available upon request (except in the case of confidential information).

The research method is composed of five sequential and interdependent stages as illustrated in Figure 3. Such stages, in which different research activities and developments take place, are analogous to the ones suggested above by different authors in the field of Constructive Research as discussed in section 2.2.

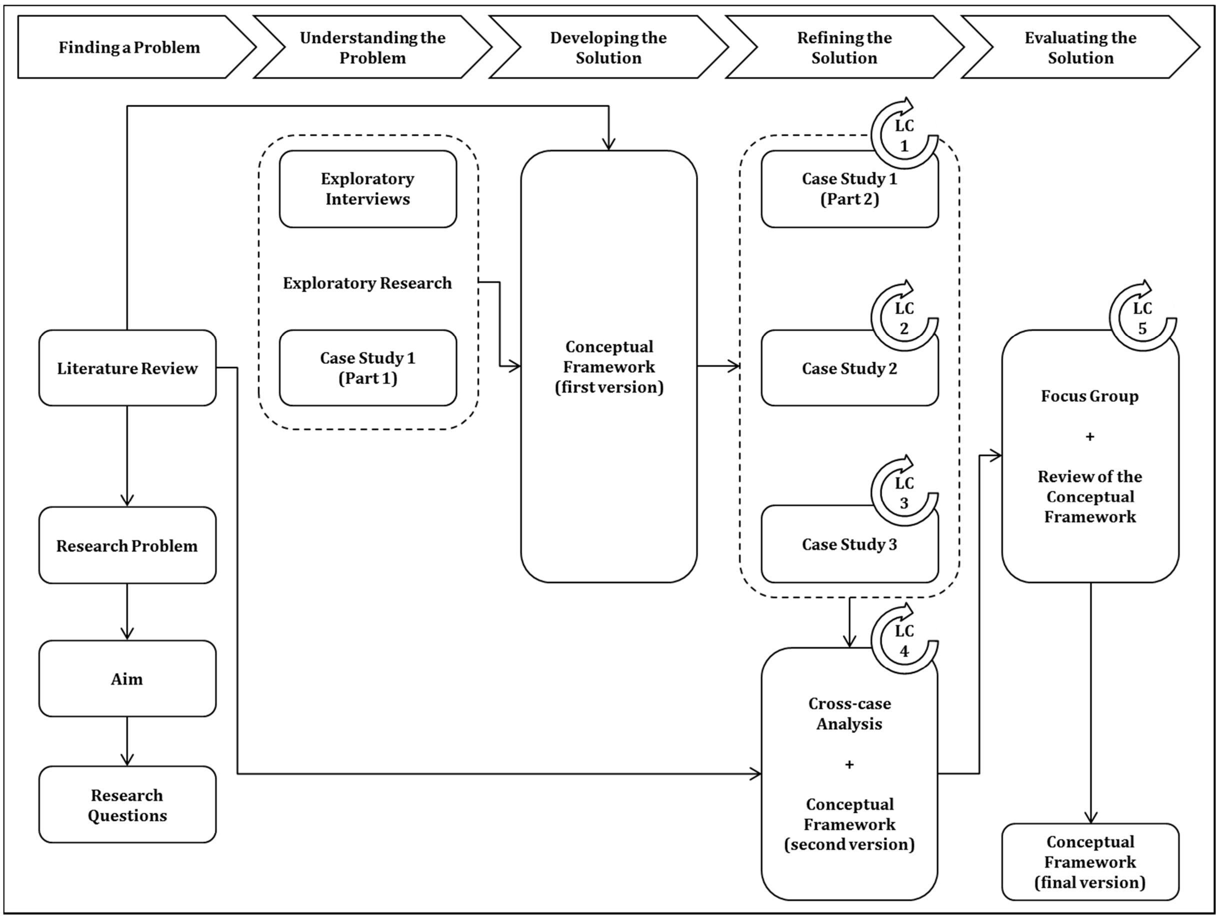


Figure 3 – Research method

The stages of the research method are presented in separate chapters as follows:

- **Finding a Problem** (Chapter 1 and Chapter 3);
- **Understanding the Problem** (Chapter 4);
- **Developing the Solution** (Chapter 5);
- **Refining the Solution** (Chapter 6);
- **Evaluating the Solution** (Chapter 7).

2.3.1 Finding a Problem

This stage comprises the review of the literature, the definition of the research problem, the delineation of the aim, and the proposition of research questions.

2.3.1.1 Literature Review

According to Creswell (2013), the literature review provides the researcher with results from other studies related to the one being carried out, relates the current study to the larger and current literature, positions the relevance of the study in a broader context, and enables benchmarking for comparative purposes. In this study, the literature review is presented in Chapter 3. In order to prepare the review, a systematic approach was adopted. According to Tranfield *et al.* (2003), systematic reviews encompass a process that minimizes bias and synthesizes the relevant body of knowledge in a determined field. In this research, such a process is represented by two steps, to be presented in the subsequent sections. Step 1 comprises the identification of keywords and publications and Step 2 the selection of papers and summarization of findings in the literature.

2.3.1.1.1 Step 1 – Identification of Keywords and Publications

First, a set of keywords were identified by the researcher: supply chain management, construction, best practices, model, and framework. Such keywords were checked in different databases including the following but not limited to them: EBSCO, Web of Science, Google Scholar, Scopus, Science Direct, Emerald, and Elsevier.

Next, papers from a wide range of journals in the fields of Production, Construction, and Supply Chain Management were reviewed. The list of journals investigated in this research includes the following but it is not limited to them:

- International Journal of Production Economics;
- International Journal of Production Research;
- Supply Chain Management: An International Journal;
- International Journal of Physical Distribution and Logistics Management;
- International Journal of Logistics Management;
- International Journal of Operations and Production Management;
- Construction Management and Economics;
- Journal of Business Logistics;
- Production Planning and Control;
- Building Research and Information.

Such journals were selected based on their impact factor and their relevance in the field of this research. Papers in the Proceedings of the International Group for Lean Construction (IGLC) conferences were also reviewed. Additionally, a number of books were used as key points in the literature during the development of this thesis.

2.3.1.1.2 Step 2 – Selection of Papers and Summarization

The most relevant literature topics to be investigated and the key papers for each topic are selected and grouped properly, and they are presented in chapter 3. Such literature was then summarized in order to provide information for different topics, constituting three main sub-sections in chapter 3:

- **General Characteristics of Production and Construction:** the key production processes and strategies are presented in order to provide context for this research. In addition, a discussion regarding the concept and the relevance of the order penetration point is introduced. Finally, the key competitive priorities for operations management are highlighted. The nature of the project-based production system is presented, followed by the characteristics of multiple and concurrent projects, existence of dispersed site locations, and uniqueness of projects;
- **Supply Chain Management in Production and Construction:** a discussion regarding the concept of supply chain management is introduced. Two frameworks for managing supply chains in the manufacturing sector are presented and their key features emphasized. Next, best practices in supply chain

management are discussed. Six key characteristics of construction supply chains are emphasized: project-based chains, specific network design, interfaces, supplier base, fragmentation, and demand forecast;

- **Conceptual Views of Production and Supply Chain Management:** a set of existing theories and approaches related to production and supply chain management is presented.

2.3.1.2 Research Problem, Aim and Research Questions

The research problem, aim, and research questions were presented in chapter 1. By reviewing such breadth of literature, the body of knowledge supporting this research was developed. The research problem is presented as follows:

> *The research problem to be addressed in this study is the lack of a contextualized, structured, and long-term oriented framework for designing and improving construction supply chains from the viewpoint of a construction company.*

Table 2 lists the research questions, which are used to guide the investigation of the research problem. The idea was to link the questions with existing gaps in the literature to be addressed in this research. By answering the questions, the overall aim of this investigation should be achieved.

Table 2 – Aim and Research Questions

Aim
The aim of this research is to develop a conceptual framework and best practices to tackle the problems of construction supply chains.
Research Questions
How should construction supply chains be conceptualized in a framework?
How can the problems of construction supply chains be located?
How can practices be selected, assessed, cross-referenced, and consolidated in a framework?
How can a set of practices be adopted by construction companies for tackling supply chain problems?

2.3.2 Understanding the Problem

The strategy adopted for achieving a better understanding of the problem is based on exploratory research. Two activities were developed: a set of exploratory interviews and a case study.

2.3.2.1 Exploratory Interviews

In order to understand the current scenario of construction supply chains, a set of interviews was conducted with academics and practitioners. Such interviews were developed between November 2012 and February 2013, and each interview took approximately 60 minutes. Further details regarding exploratory interviews are presented in section 4.1 and in Appendix A – Interview Protocol.

A semi-structured questionnaire was prepared in order to support the interview process. The interviews and questions were aimed at exposing what initiatives, practices, guidelines, and issues there are in managing construction supply chains. In order to introduce the discussion and support the justification of this research, the following question was posed to the interviewees '*Is a contextualized framework to manage construction supply chains necessary?*'. The word contextualized was used in order to define that the framework should address the specificities of a context: construction companies building infrastructure projects. Data collected from the interviews was transcribed and categorized. Data categorization was deployed via two foci. The primary aims at finding the strategic relevance fostering the development of a framework for managing construction supply chains. The secondary endeavours to describe the relevant elements pointed out by the interviewees for designing and improving construction supply chains.

2.3.2.2 Case Study 1 (Part 1)

Case Study 1 was developed in Company A, which is a major construction company in Brazil. The case study was divided into two parts, namely Part 1 and Part 2. Part 1 has an exploratory nature and it was conducted between May 2013 and September 2013, including mostly activities for collecting and analysing information. This schedule comprised nine weeks in a row for conducting semi-structured interviews, participation and observation of meetings, one workshop with suppliers, collection of documents, and site visits among others. In order to facilitate the understanding of the reader, full details regarding Case Study 1 (Part 1) are reported in section 4.2.

2.3.3 Developing the Solution

This stage of the research method comprises the development of the conceptual framework. According to the proposition of constructive research, the first solution is also referred to as candidate solution. In this research, first or candidate solution is also called first version of the framework. As illustrated in Figure 4, three inputs were considered for developing the first version of the conceptual framework.

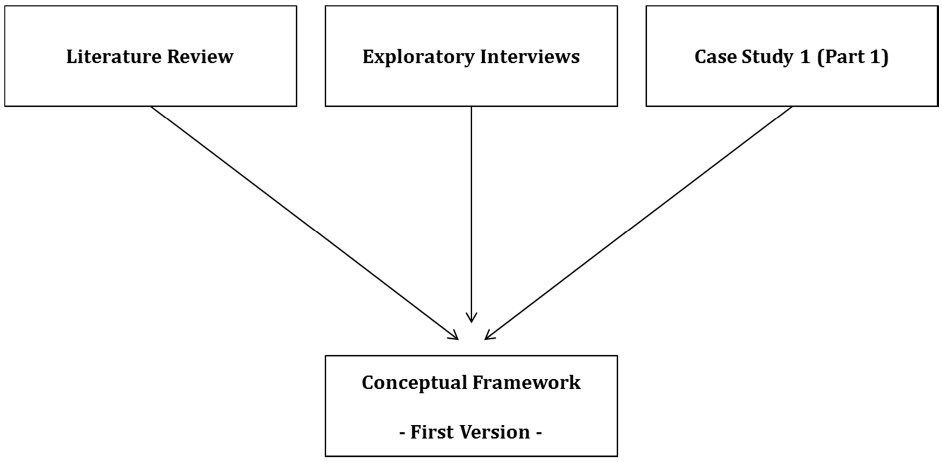


Figure 4 – Inputs for developing the first version of the conceptual framework

The development of the candidate solution is detailed in chapter 5. Such a solution comprises two fundamental elements, which are later refined and tested as part of the DSR approach.

- **Conceptualization of construction supply chains:** as discussed earlier in chapter 1, the need for a contextualized framework for managing supply chains in the heavy construction sector is the central motivation of this study. However, in order to contextualize such a framework a previous conceptualization is therefore required. The key points considered for conceptualizing construction supply chains in the heavy infrastructure sector are the intrinsic characteristics of construction companies and the specific features of construction supply chains in such a sector. In addition, current frameworks for managing make-to-stock supply chain structures were analysed in order to understand whether some of their components could be adapted and then incorporated in the candidate solution. Three essential foundations are then proposed for conceptualizing construction supply chains, namely interfaces, flows, and key parties involved. As proposed in the DSR approach, such conceptualization will be refined in further stages of this research;

- **Practices for construction supply chains:** after conceptualizing construction supply chains, it was found that an additional element for supporting such conceptualization becomes necessary. As discussed earlier in chapter 1, there are three essential actions in production systems: design, operation and control, and improvement. The task of managing construction supply chains is seen as analogous to production management in this study. The additional element in the conceptual framework is a set of practices focused on the design and improvement of construction supply chains. The practices provide basis to sustain construction supply chains in the long run. Based on the existing literature, an initial set of practices for designing and improving construction supply chains was then proposed. Based on the DSR approach, such set of practices will be refined in further stages of this research.

2.3.4 Refining the Solution

Refining the solution is proposed as the next stage in the research method. Such refinement has as its starting point the first version of the conceptual framework. In order to accomplish such refinement, three case studies were developed based on a set of research activities, including semi-structured interviews, participation and observation of meetings, and collection of documents:

a) **Semi-structured interviews**, according to Bryman and Bell (2011), constitute a wide approach for collecting expressions and opinions from interviewees without forcing them to choose specific options. Semi-structured interviews should be flexible, which positions them between a structured and an unstructured approach of interviewing. On the one hand, structured interviews require the participant to respond to pre-determined questions and coded answers, as the ones that typically appear on surveys (May 2011). On the other hand, unstructured interviews are guided towards a specific theme defined by the interviewer, and they have an open-ended character (May 2011). The idea behind semi-structured interviews is that participants are encouraged to discuss their ideas based on a pre-defined framework, which contains an initial set of questions. In the present research, questions were prepared in advance of interviews, but they did not necessarily follow their original order. This flexibility was necessary so that emerging topics in interviews were properly addressed with interviewees. The interviewees received information prior to the interview, they had time for questioning, and they were interviewed in a private environment. Yin (1994) discussed a set of weaknesses of semi-structured interviews, including response to bias and imprecisions in recalling data. In order to tackle such limitations, interviews in this research were recorded and summarized for future reference.

b) In this research, **the observation of practices and participation in meetings** was conducted along with case studies. The main purpose of the observations is to gather information about the practices conducted by the companies in terms of performance evaluation, the assessment of suppliers, mid and long-term decisions regarding supply chains, among others. Creswell (2013) defined an observation as the moment in which the researcher observes the behaviour and activities of individuals in the field. Saunders *et al.* (2009) stated that such an approach comprises systematic observation, recording, transcription, analysis, and interpretation of the participant's behaviour.

c) In this research, free clearance to **examine documents** was arranged in the different companies, although access to financial data was restricted. Nevertheless, such restriction has not produced any limitation regarding the focus of this research. The majority of documents analysed comprised procurement orders, metrics, action plans, improvement guidelines, managerial frameworks, dashboards, and procedures, among others. In addition, time slots were allocated in the research schedule especially for assessing and reviewing such documents. Documents of a public and private nature (Creswell 2013) are usually analysed in the process of research. Yin (1994) highlights that documentation in a case study is necessary in order to substantiate and enhance evidence from other sources. In addition, according to Yin (1994), the following points are related to documentation, (i) documents are helpful in verifying the correct spelling titles or names of organizations previously mentioned in interviews, (ii) documents can provide other specific details to corroborate information from other sources, and (iii) inferences can be made from documents.

In this research, the above-mentioned approaches were carried out within case studies. Case studies were developed according to the general proposition of Yin (1994). This research focuses on multiple case studies for replication purposes. Replication is used in order to check if different cases produce similar results (Yin 1994), and enables the outputs from each case to be systematically compared in a cross-case analysis. The reports of the case studies presented in chapter 6 were prepared following the same structure:

- An introduction demonstrating the research activities carried out and relevant information about the context;
- A detailed report regarding the practices investigated;
- A discussion regarding the lessons learned.

Flyvbjerg (2006) discusses case studies and the common misunderstandings surrounding this research approach:

- Context-independent knowledge is more valuable than concrete and practical (context-dependent) knowledge;
- One cannot generalize on the basis of an individual case;
- The case study is most useful for generating hypotheses;
- It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies.
- The case study contains a bias toward verification, that is, a tendency to confirm the researcher’s preconceived notions;

According to Flyvbjerg (2006), these misunderstandings are especially related to the validity, reliability, and theoretical contribution of case study as a scientific method. Hodkinson and Hodkinson (2001) emphasize the strengths and limitations of case studies. On the one hand, these authors argue that cases help to understand complex inter-relationships because they are grounded on reality, as well as they facilitate the exploration of unexpected or unusual phenomena. On the other hand, the same authors discuss a set of limitations regarding the utilization of cases, including the amount of data to be collected and then analysed, the complexity in representing the reality found, the difficult in providing generalization, among others.

2.3.4.1 Case Studies

Information regarding Companies A, B, and C are summarized in Table 3. Companies A, B, and C have different projects, ranging from highways and tunnels to airports.

Table 3 – Companies selected for case studies

	Company A	Company B	Company C
Country	Brazil	UK	UK
Nature	Private	Private	Public
Revenue/CAPEX (per year)	£150 M (Revenue)	£900 M (Revenue)	£4 B (CAPEX)
Employees (number)	2,500	3,300	N/A
Supplier Base (number)	4,200	1,200	N/A
Suppliers in the Research Process (number)	11	N/A	6

The aforementioned companies are located in two different countries in which the construction sector has a major influence in the economy. The selection of the cases was based on the following underpinnings: diversity of projects, location, corporate culture, availability, and type of ownership.

The unit of analysis in this research comprised three different levels. First, the Enterprise Level of the construction companies was analysed. The majority of research activities (i.e. interviews) were conducted at this level, especially to determine the extension and the type of data to be collected in two other levels: Supplier Level and Project Level. On the level of suppliers, tier-one and tier-two suppliers were involved (where applicable) in the different case studies. The characteristics of suppliers approached differ significantly in terms of scope, size, and revenue. On the level of projects, existing project sites were visited and professionals in the respective teams were interviewed.

2.3.4.1.1 Case Study 1 (Part 2)

Case Study 1 was developed in Company A, which is one of the top-50 construction companies of Brazil in revenue. Company A is focused on building infrastructure projects (i.e. tunnelling, highways, earthworks) throughout the country. Company A expects annual revenue of £150 million on average, has 2,500 employees approximately and 4,200 active suppliers. Company A is also part of a holding with initiatives not only in the construction sector but also as an automobile dealer, among others. Company A has a very strong business culture and is family-owned. Case Study 1 was divided in two parts, namely Part 1 (exploratory research) and Part 2. In order to facilitate the understanding of the reader, full details regarding Case Study 1 (Part 2) are reported in section 6.1 and in Appendix B – Log of Activities.

2.3.4.1.2 Case Study 2

Case Study 2 was carried out in Company B, a large UK-based contractor focused on infrastructure projects such as highways, earthworks, airports, and railways, among others. Company B expects annual revenue of £900 million, has 3,300 employees, and 1,200 active suppliers approximately. The study took place from March 2014 to August 2014 and its full details are reported in section 6.2 and in Appendix C – Log of Activities.

2.3.4.1.3 Case Study 3

Case Study 3 was conducted in a government organization in the UK. In order to keep consistency in the terminology adopted in this research, this organization is named Company C. The organization is responsible for operating, maintaining, expanding, and improving strategic infrastructure assets. Company C has two predominant categories of infrastructure developments: those carried out by the Major Projects Directorate (major national significant schemes) and those carried out by the Network Delivery and Development Directorate (smaller local improvement and maintenance schemes). Company C has a strong governance role in the construction sector in the UK, given its high profile as a client of major contractors. Reports indicate an annual CAPEX (Capital Expenditure) of around £4 billion in its two categories of infrastructure developments. The study took place between August 2013 and August 2014 and its full details are reported in section 6.3 and in Appendix D – Log of Activities.

2.3.4.2 Structure of Case Studies

The three case studies were structured similarly. The structure was conceived in order to keep simplicity and consistency throughout the different cases. Such a structure is composed of identification and selection of practices, preparation and conduct of interviews, collection of documents, and participation in meetings. Case studies contributed as well to validating the conceptualization of construction supply chains, which is the first element of the proposed conceptual framework. Further information regarding the research process developed in the cases is presented in Appendix E – Case Study Protocol.

Companies were initially approached in order to identify their practices for managing supply chains. Such an approach was conducted in face-to-face and teleconference meetings. Company A participated early in this research in its exploratory stage and it was again approached for contributing to the framework refinement. Research proposals were forwarded to Company B and Company C in order to formalize their participation in the present research.

First, 'best-practices' identified in Companies A, B, and C were selected. The following criteria were used for selecting such practices: relevance and novelty, availability of participants, time required for completing the studies, and level of confidentiality of information.

Second, the interviews were prepared in order to capture *how* Companies A, B, and C developed, implemented, and learned from the practices investigated. Questions for semi-structured interviews were prepared ahead of each interview in order to guide the process. Participants were communicated with in advance so that appropriate conditions for the interviews could be arranged. The interviews took 60 minutes on average, and they were recorded for future reference.

Third, documents were collected during the case studies. Such documents provide evidence of the practices reported by companies. Some of the documents include procedures, guidelines, reports, and dashboards, among others. Documents were analysed, compared, and physically or digitally archived.

Finally, meetings were observed in case studies. The role of the author of this thesis was defined as a non-participant observer. Such observations were registered, organized, and later summarized.

This research contains multiple sources of data, including semi-structured interviews, observation of meetings, and documents, among others. These different sources of data were cross-referenced in order to triangulate the evidences found in each of them. Interviews were recorded and summarized in individual files for future reference. Documents were catalogued according to the information contained on them. Due to the nature of the data in this research, no specific software was used in data analysis. However, a coding system using colours and specific notes was applied when cross-referencing sources of data. Colours were used to identify similar topics or subjects in the discussion, while notes were used as personal memos regarding the topics under analysis. This approach was replicated across all case studies developed in this research.

2.3.4.2.1 Learning Cycle of Case Studies

A Learning Cycle (LC) is planned at the end of each case study. Learning cycles were used as a strategy to capture the individual contributions of case studies for refining the first version of the conceptual framework. In the next sections of this chapter, other types of learning cycles are presented not in the context of case studies, but in the context of the cross-case analysis and the focus group. Questions are used as a script for systematically checking the contribution of the cases. The proposition of the DSR approach is to use learning cycles as a reflection upon the work developed. Such reflection enables the researcher not only to refine the artefact but also to assess the theoretical implications during its development. In this sense, LC simplifies the task of tracking research contributions as they evolve.

The learning cycles of case studies is illustrated in Figure 5.

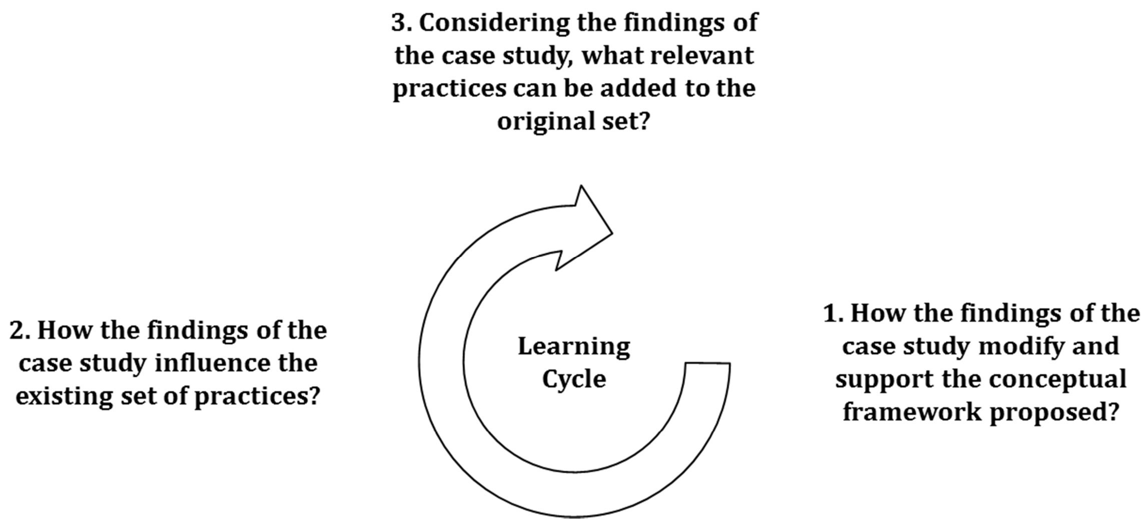


Figure 5 – Learning cycle of case studies

The initial questions proposed are:

- How the findings of the case study modify and support the conceptual framework proposed?
- How the findings of the case study influence the existing set of practices?
- Considering the findings of the case study, what relevant practices can be added to the original set?

2.3.4.3 Cross-case Analysis

A cross-case analysis was carried out after case studies were completed. The idea of having a cross-case analysis was motivated by the opportunity to gather and analyse the differences and similarities found in each case study. By having a cross-case analysis, additional insights can be incorporated in the refinement of the conceptual framework.

Cross-case analysis is divided in two parts. First, the studied companies are compared in terms of their differences and similarities concerning the conceptualization of construction supply chains. Such comparison emphasises the way in which Companies A, B, and C can be compared in terms of the parties involved, types of flows, and interfaces found in their supply chains. Second, the practices extracted from the cases are cross-referenced (where applicable) in terms of their description, positive aspects, and recommendations for improvement. Additional findings in the literature regarding the practices extracted in the cases are included where applicable. Finally, a set of 'best practices' is proposed as illustrated in Figure 6.

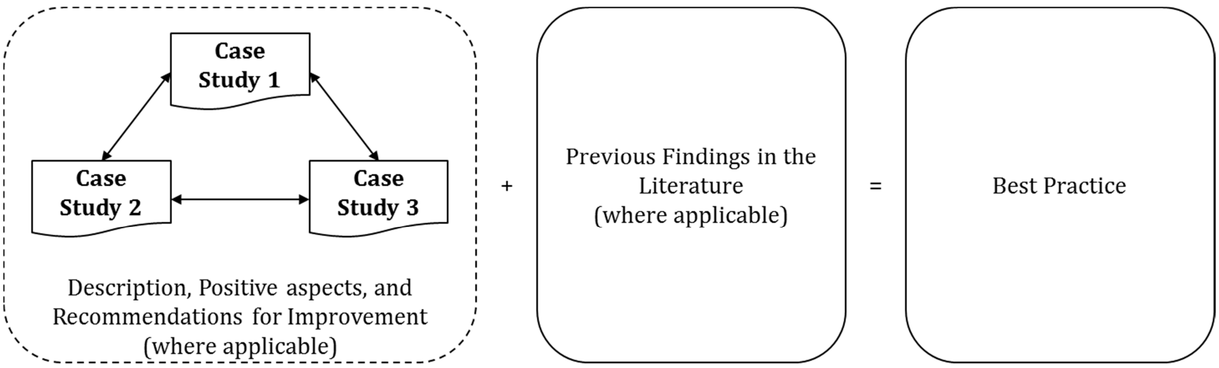


Figure 6 – Generation of 'best-practices'

2.3.4.3.1 Learning Cycle of Cross-Case Analysis

A Learning Cycle is planned for the cross-case analysis in order to capture the integrated contribution of case studies as illustrated in Figure 7. As discussed in section 2.3.4.2.1, learning cycles help to track the contributions throughout the research process.

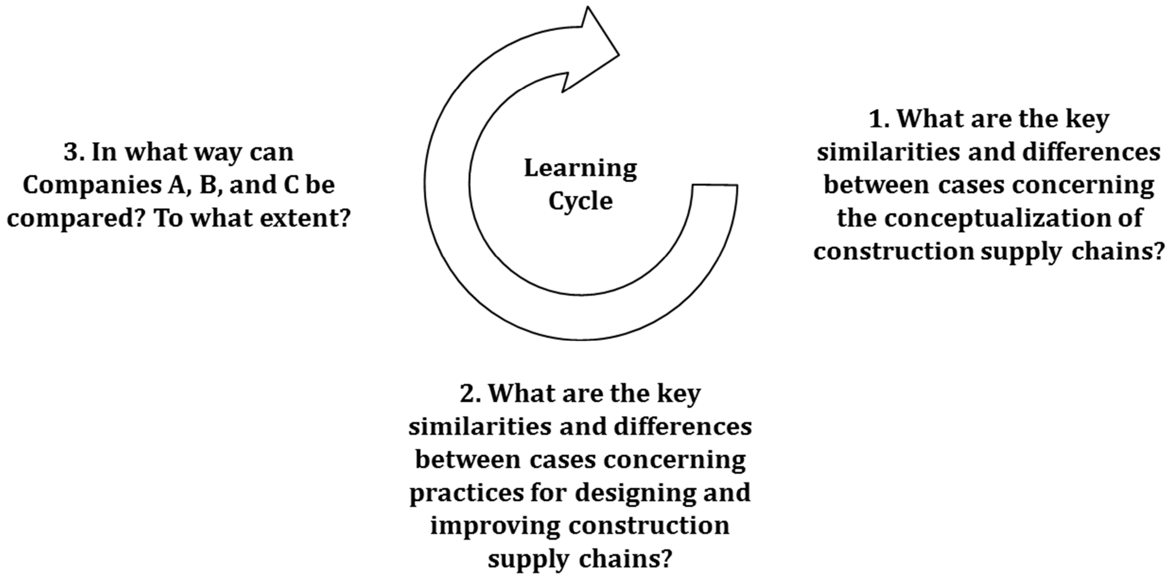


Figure 7 – Learning cycle in cross-case analysis

The questions below are used as a script to check the contribution of the cross-case analysis:

- What are the key similarities and differences between cases concerning the conceptualization of construction supply chains?
- What are the key similarities and differences between cases concerning practices for designing and improving construction supply chains?
- In what way can Companies A, B, and C be compared? To what extent are they similar to each other?

2.3.5 Evaluating the Solution

Evaluating the solution is proposed as the final stage of the research method. In order to evaluate the conceptual framework, after the refinement process is completed, a focus group is proposed. The focus group report and the final version of the framework are detailed in chapter 7.

2.3.5.1 Focus Group

Saunders *et al.* (2009) defined focus group as a particular case of group interview in which the topic is clearly defined, and the researcher wants to register collaborative discussion between participants. Focus groups differ from group interviews because the researcher encourages the participants' involvement and controls the focus of the discussion. In addition, the researcher has a moderator role by keeping the group within the limits of the subject being debated and not guiding the group towards determined ideas (Saunders *et al.* 2009).

According to May (2011), a focus group can provide substantial insight in the examination of particular topics or processes. The same author argues that the outcome of focus groups might present additional results, which can be combined with those obtained in individual interviews about the same issues. Differences in the results gathered in the focus group and in interviews are attributed to the natural way in which actions and opinions are affected by other participants (May 2011). Bertrand *et al.* (1992) contend that focus group research is often criticized in terms of generalizability, given that a small number of participants may not represent the characteristics of a target population.

The second version of the framework, generated after the cross-case analysis, is then presented to the focus group. A presentation summarizing the conceptualization of construction supply chains and the set of practices is used to guide the discussion. The focus group is chosen as a strategy for evaluating the conceptual framework due to its intrinsic nature: gather a group of experts in a particular field for discussing a certain topic. Full details regarding the focus group are provided in section 7.1.

The objectives of the focus group discussion include the following:

- Discuss the applicability of the conceptual framework proposed;
- Understand and register the perceptions of the participants regarding the conceptualization of construction supply chains;
- Comprehend and catalogue the observations of the participants about the practices for designing and improving construction supply chains.

2.3.5.1.1 Learning Cycle of Focus Group

A final Learning Cycle is planned for the focus group in order to capture the contribution of the discussion as illustrated in Figure 8. Lessons learned in this cycle are used as an input for conceiving the final version of the conceptual framework, which is presented in section 7.2.

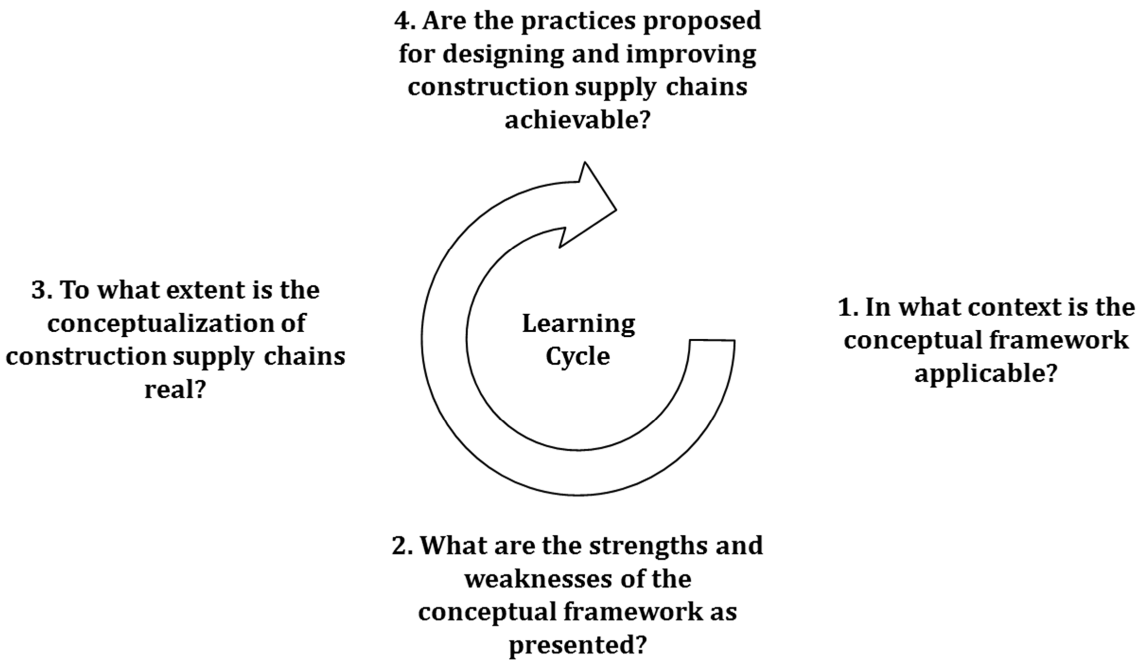


Figure 8 – Learning cycle in focus group

In order to assess the contribution of the focus group, the following questions are proposed:

- In what context is the conceptual framework applicable?
- What are the strengths and weaknesses of the conceptual framework as presented?
- To what extent is the conceptualization of construction supply chains real?
- Are the practices proposed for designing and improving construction supply chains achievable?

3 LITERATURE REVIEW

Construction supply chains are problematic to manage. These supply chains have multiple parties involved that interact on a project basis. Although these interactions are temporary from the point of view of the project, they last over time when it comes to viewpoint of the enterprise. In the particular case of construction, much attention in the literature has been focused on managing project supply chains rather than the enterprise supply chain. The main difference between these approaches is the planning horizon, given that the first one is focused on short-term and temporary decisions, and the latter is devoted to long-term oriented thinking. The research problem to be addressed in this study is the lack of a contextualized, structured, and long-term oriented framework for designing and improving construction supply chains from the viewpoint of a construction company.

The literature review in this study is focused on three streams. These streams are reviewed so that both general and specific backgrounds are discussed, analysed, and summarized. The first stream is the one related to **General Characteristics of Production and Construction**. The characteristics of construction are highlighted and compared to the ones in production. The second stream is the one associated with the **Origins, Current Status, and Context of Supply Chain Management**. The review starts with the concept of supply chain management according to different authors. Next, the well-known SCOR and GSCF models, which were developed in the manufacturing sector, are presented and analysed. The review continues with an analysis of the existing best practices in the field of supply chain management. Finally, the particular literature in the field of supply chain management in construction is presented and discussed. The third stream is the one related to the **Conceptual Views of Production and Supply Chain Management**. Research developments in both fields are discussed, analysed, and referenced so that they can provide a theoretical basis for this research.

3.1 General Characteristics of Production and Construction

First, this section revises the general characteristics of production in terms of its processes, strategies, order penetration points, and competitive priorities. When examined together, such characteristics create a significant range of possibilities to be selected by a company for managing its operations. Second, key aspects of construction in light of the above-mentioned background of production are reviewed. The general aspects of construction reviewed in this section comprise its project-based nature, the existence of multiple and concurrent projects, the dispersed site locations, and the uniqueness of schemes.

3.1.1 Characteristics of Production

Production is examined in the following streams: processes, production strategies, order penetration points, and competitive priorities.

3.1.1.1 Production Processes

The proposition of different production processes derived from the interactions between process and product features (Hayes and Wheelwright 1979a). In this sense, production processes were determined by the intrinsic characteristics of the products they manufacture and their process requirements. The volume of production, the mix of products, the level of customization, the sequence of tasks to be performed, the nature of the flows, the degree of repeatability of work, among others, are the key aspects to be considered when matching product-process features (Hayes and Wheelwright 1979a).

Figure 9 presents the positions (also called process choices) in the product-process matrix (Krajewski *et al.* 2007). Such matrix defined five major process choices connecting the manufactured product with the process: Continuous flow process, Line process, Large batch process, Small batch process, and Job process. The process choices can be selected for the entire plant or just for a single sub-process within it (Krajewski *et al.* 2007).

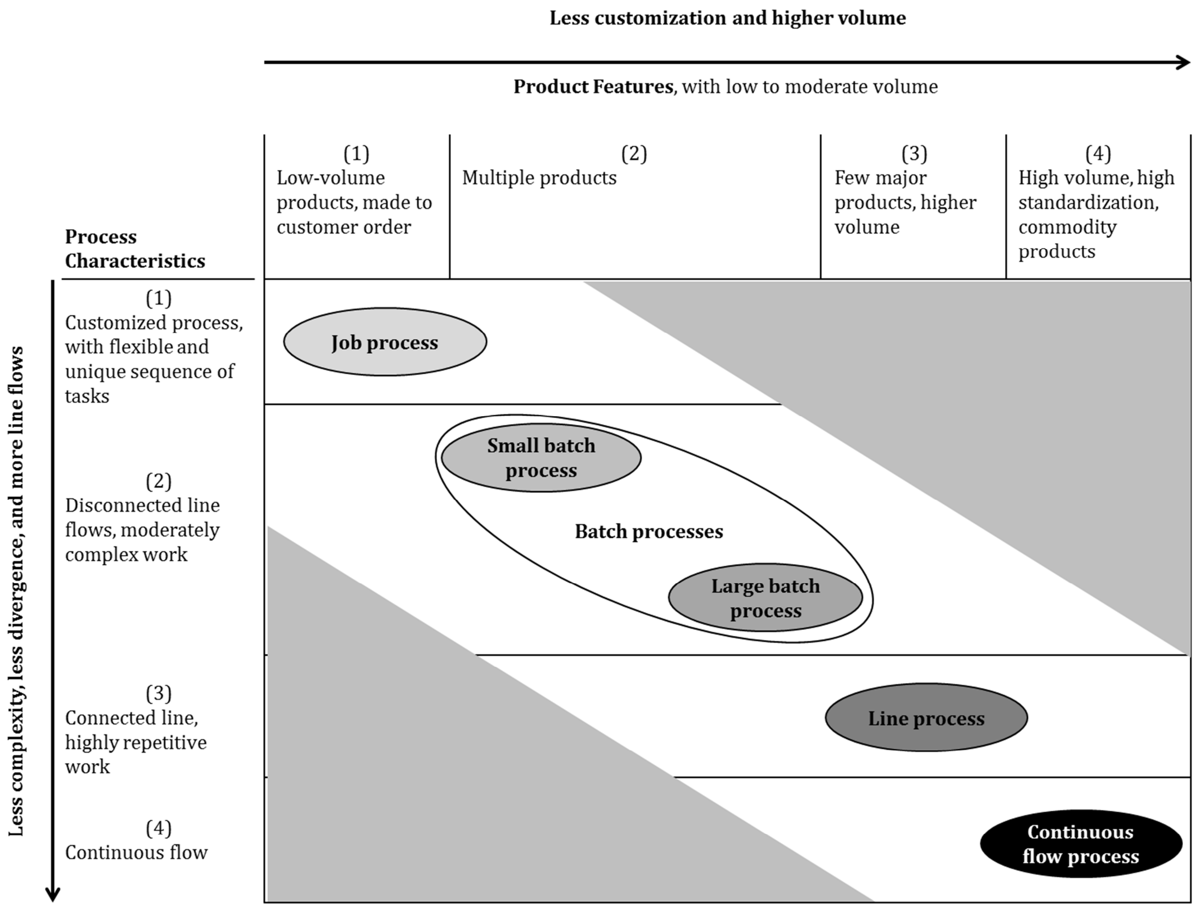


Figure 9 – Product-Process matrix for processes (Krajewski *et al.* 2007)

The types of process choices are listed below:

a) **Continuous flow process**: is situated at one of the borders of the product-process matrix. This approach for production is concerned about products with high volume and a commodity market position in many cases (Hayes and Wheelwright 1979a). Also, the process is characterized by a continuous, in many cases sealed, flow (Krajewski *et al.* 2007). This production process is suitable for areas within the chemical industry such as oil, gas, and plastic.

b) **Line process:** is the traditional manufacturing approach. Such an approach is related to products with high demand volume. The high level of demand requires that the production process presents connected flows and repetitive and standardized work (Hayes and Wheelwright 1979a). This approach for production is applied in a variety of industries, such as computers and technology, small electric appliances, shoes, among others.

c) **Large batch process**: is situated at the midpoint position in the product-process matrix (Krajewski *et al.* 2007). This type of production process is adequate for multiple products with a moderate to high volume of production (Hayes and Wheelwright 1979a). In addition, large batch process presents characteristics of both connected and disconnected lines and both complex and repetitive work. This production process is suitable for heavy industry, such as steel, mining, and cement.

d) **Small batch process:** aims at manufacturing low to moderate volumes and a large variety of products. In this sense, small batch processes are used as a manufacturing approach to produce parts and components that could be assembled later via job process. Such parts and components present a low repetitive pattern, but they can usually be used in different products manufactured within the same plant or company. Kemppainen *et al.* (2008) associate batch process with disconnected line flows and discrete manufacturing capability. Krajewski *et al.* (2007) state that usually a batch of one product is processed at each time: in scheduling, production is switched to the next product to be manufactured. In some cases, a batch of the first product is produced again. Ariss and Zhang (2002) discuss that some batch processes use different strategies to produce standardized products in moderate volumes, including mass customization. Although the volume of production ranges from low to moderate, the variability within production is too high to dedicate a special area in the shop floor to each product (Krajewski *et al.* 2007). Small batch process is commonly applied in the aircraft and heavy equipment industries combined with job process.

e) **Job process:** is also known as project-based process (Slack *et al.* 2007), and aims at producing a variety of products in significant quantities, considering high complexity tasks and divergence in the steps throughout the production process. Kemppainen *et al.* (2008) argue that the labour intensity is different across the different production processes: job process usually requires more operators for individual machines in the shop floor. Johansson and Olhager (2006) discuss that the production processes are classified based on their flow: job process presents the lowest level of flow orientation within the product-process matrix. Krajewski *et al.* (2007) characterize job process by stating that such a production approach allocates the resources around itself. In addition, Krajewski *et al.* (2007) highlight that flexibility is a key competitive priority to achieve full operation in job process. Even though job process presents considerable variability, some line flows can be implemented within it due to similar orders from customers. Finally, job process is commonly applied in construction and shipbuilding industries. As project-based process is closely related with the construction industry, it will be detailed further in section 3.1.2.1.

3.1.1.2 Production Strategies

As mentioned above, there is a range of production processes derived from the interaction between process and product features. However, each of the production processes requires a specific strategy to be properly operated. The different production strategies have been investigated in the operations management literature over the last 30 years, and they are presented as Make-to-Stock, Assemble-to-Order, Make-to-Order, and Engineer-to-Order (Hayes and Wheelwright 1979a; Olhager and Ostlund 1990; Olhager 2003; Johansson and Olhager 2006).

The choice of a production strategy must be based on the characteristics of the product to be manufactured (Fisher 1997). Volume of production, degree of customization of the product, degree of involvement of the suppliers, types of production processes, (Choi and Linton 2011), and demand patterns (Slack *et al.* 2007), among others, comprise the issues that must be evaluated in order to position a production strategy.

Even though the concepts of production strategies are simplistic, their wide adoption took many years to be better developed and understood by companies. Sharman (1984) stated that every make-and-sell business is a system for designing, producing, and delivering goods to customers. In such study, Sharman (1984) compared different manufacturers in terms of their average days of inventory, and mapped their general production stages from suppliers to customers, discussing the findings in terms of production strategies.

The list below introduces the different production strategies:

a) **Make-to-stock:** involves the production of goods prior to their being demanded by customers (Slack *et al.* 2007). This production strategy is highly recommended for standardized products, which should be produced in high volumes driven by demand forecast (Krajewski *et al.* 2007). Normally, these products fit the characteristics described by Hayes and Wheelwright (1979a) for Line or

Continuous processes. Typical products manufactured with a make-to-stock production strategy comprise garden tools, soft drinks, electronic components, and chemicals, among others (Krajewski *et al.* 2007).

b) Assemble-to-order: comprises the production of a wide range of products after the customer's order is received (Krajewski *et al.* 2007). This production strategy is proposed for products that can be produced by combining pre-assembled and standardized parts. Such parts might be produced in line and batch processes, previously described by Hayes and Wheelwright (1979a): different batches can be prepared until the customer's order arrives, and afterwards such batches might be combined in order to produce the final product. Given such production nature, the postponement approach is widely applied in assemble-to-order production strategy (Krajewski *et al.* 2007). Typical products manufactured with an assemble-to-order production strategy include paint, prefabricated furniture, computers, among others (Krajewski *et al.* 2007).

c) Make-to-order: involves the production of specific products following the customer's specification and attending specific orders (Slack *et al.* 2007). Such a production strategy is aligned with low volumes of production and increased customization of the final product, which is suitable for Job or Small batch processes (Hayes and Wheelwright 1979a). Increased flexibility is recommended throughout the entire production process (Krajewski *et al.* 2007). Typical products produced with a make-to-order production strategy comprise medical equipment, castings, among others (Krajewski *et al.* 2007).

d) Engineer-to-order: comprises the fabrication of specific products according to specific design, technical requirements, and attending specific orders placed by customers. In this sense, the engineer-to-order production strategy is commonly associated with highly customized products and a typical project-based production process (Gosling and Naim 2009; Gosling *et al.* 2013a). Project-based processes are suitable for low volumes, and increasingly customized products (Hayes and Wheelwright 1979a). Typically, the engineer-to-order production strategy produces capital equipment for the power, materials handling, and offshore industries (Hicks *et al.* 2000), and the construction sector (Gosling *et al.* 2013a; Hicks *et al.* 2001), among others.

3.1.1.3 Order Penetration Point

The concept of Order Penetration Point (OPP) has arisen from mapping different stages in a production system from suppliers to manufacturers (which later has been called the supply chain). Typically, these stages are design, procurement and fabrication, final assembly, and shipment (Olhager 2003). Sharman (1984) has discussed the OPP in terms of its implications in operational aspects (logistics) and its impacts in the overall production strategy of a company.

Later, Olhager and Ostlund (1990) have linked the concept of the OPP with a manufacturing approach, naming the point as Customer Order Point (COP). According to Olhager and Ostlund (1990), the COP is the point in the manufacturing process in which the product is assigned to a particular customer order. The COP also has a strong relationship with customization: it is the point in which the customer inputs are incorporated by the production process. In this context, Olhager and Ostlund (1990) have also presented a major contribution derived from the COP: the need for different production approaches upstream and downstream the COP. Studies regarding *leagile* production management such as Mason-Jones *et al.* (2000) and Naim and Gosling (2011) discuss such topic in depth, as shown in section 3.3.2.

Olhager (2003) presented the direct relation between production strategies, different production activities, and the positioning of the decoupling point as shown in Figure 10. The OPP positioning refers to demand aspects that produce supply chain implications. On the one hand, Olhager (2003) stated that production downstream the OPP is driven by real demand, which means that a real order was placed. Conversely, production upstream the OPP is based on demand forecast. Such understanding is relevant for planning aspects, once the company is able to realize in which horizontal position its OPP is located (Olhager 2003). On the other hand, supply chain is highly influenced by the positioning of the OPP, once suppliers have to adapt their production approaches to cope with a customer's requirements.

Olhager (2003) presented the factors that influence the positioning of the OPP into three different categories, related to market, product, and production:

a) **Market-related factors:** are listed as delivery lead-times requirements, product demand volatility, product volume, product range and customization, customer order size and frequency, and highly seasonal demand (Olhager 2003). Such factors produce a wide range of different implications amongst the production strategies. Make-to-stock production strategy tends to manufacture goods based on demand forecasts and provide no customization for products with short lead times (Hayes and Wheelwright 1979a). Conversely, engineered-to-order products tend to be manufactured based on real orders, which attend to specific customer requirements from the design stage (Hayes and Wheelwright 1979a).

b) **Product-related factors**: are presented as modular product design, customization opportunities, material profile, and product structure (Olhager 2003). Modular design has been closely related with mass-customised products (da Silveira *et al.* 2001; Yang and Burns 2003) and represents a key factor for implementing the assemble-to-order production strategy properly (Olhager 2003). The material profile and product structure have been associated with the number of different products assembled from sub-assemblies (or fabricated parts) and components (or raw materials) (Olhager 2003).

c) **Production-related factors**: are usually attributed to production lead time, number of planning points, flexibility of the production process, position of the bottleneck, and resources with sequence-dependent set-up times (Olhager 2003). In the production context, the OPP has enabled research developments for managing not only site production, but also production and materials handling throughout the supply chain. Previous research (Mason-Jones *et al.* 2000; Naim and Gosling 2011) indicates that different supply chain approaches must be adopted upstream and downstream the OPP.

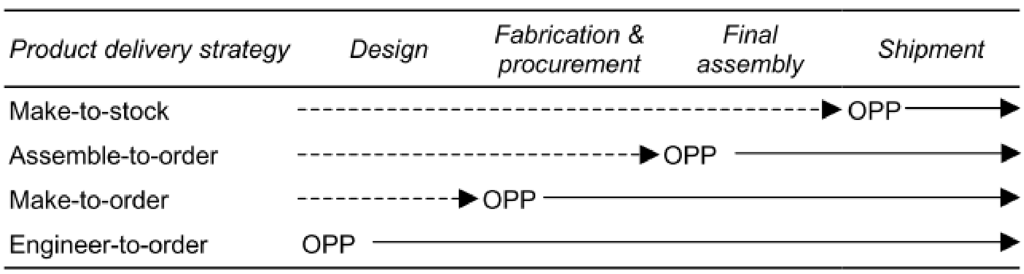


Figure 10 – Production strategies and the OPP (Olhager 2003)

3.1.1.4 Competitive Priorities

The connection between corporate strategy and operations (i.e. the manufacturing function) is critical, and it means more than high efficiency and low costs (Skinner 1969). Driving cross-functional efforts between different areas of a firm in order to operationalise a customer-driven production strategy is a complex task. Particularly in operations, there is a need for defining objectives that relate specifically to the job of attending to a customer's requirements (Slack *et al.* 2007). In this sense, competitive priorities, also referred to in the literature as performance objectives, form the key operational dimensions a process must encompass in order to match internal and external customer needs (Krajewski *et al.* 2007). Previous research has investigated the origins, the relevance, the applicability, and the implications of such priorities in companies (Krajewski *et al.* 2007; Skinner 1969; Slack *et al.* 2007; Vachon *et al.* 2009; Ward *et al.* 1998).

The number of the aforementioned priorities or objectives varies in the literature. In addition, the way in which they are organized or sub-divided also differs both in the literature and in practice. Finally, these priorities also vary within a firm, given that some of them might be more critical for a determined process (Krajewski *et al.* 2007). Slack *et al.* (2007) proposed five basic objectives that apply to all types of operation. In some business environments, additional objectives might be added in order to comply with particular needs.

The five basic objectives are listed as follows:

a) **Quality:** is highly related with conformance to a customer's expectations (Slack *et al.* 2007). Ward *et al.* (1998) reviewed eight dimensional structures for quality, including performance, features, reliability, conformance, durability, service-ability, and perceived quality. Conformance appeared as the most traditional perspective adopted in manufacturing for quality. However, Ward *et al.* (1998) highlighted that the other dimensions represent a possible basis for increasing competitiveness. Krajewski *et al.* (2007) deployed quality into two sub-dimensions, namely top quality and consistent quality. Top quality is providing superior product features, and higher customer service in terms of helpfulness, among others (Krajewski *et al.* 2007). Consistent quality is manufacturing products that match specification constantly, which is achieved by process design and intensive monitoring (Krajewski *et al.* 2007).

b) **Speed:** reflects the elapsed time (also known as lead time) between the customer's request for a product and its actual delivery (Slack *et al.* 2007). Delivery speed is critical for business and it could be improved by reducing lead times (Krajewski *et al.* 2007; Ward *et al.* 1998). Improved speed produces significant results for reducing inventories and risks in operations (Slack *et al.* 2007).

c) **Dependability:** is the idea of providing in time what the customer needs (Slack *et al.* 2007). However, such service level should be provided to the customer constantly at the same standards, which also contributes to increasing predictability. In this context, a basis for reliability in delivery boosts competitiveness for the company (Ward *et al.* 1998). Slack *et al.* (2007) indicated that dependability might override all other competitive priorities given its relevance for planning purposes. In addition, three implications of increased dependability were mapped by Slack *et al.* (2007): time compression, cost reduction, and process stabilization.

d) **Flexibility:** reflects how and at what level an operation can be changed (Slack *et al.* 2007). Previous literature indicated seven different dimenions for flexibility, including product mix, volume, changeover, modification, rerouting, material, and sequencing (Ward *et al.* 1998). Krajewski *et al.* (2007) pointed out that flexibility needs to be quick and efficient in order to be aligned with the customer's requirements. However, such changes might have implications in what the operation does, how the operation is going to do it, and when the operation is going to do it (Slack *et al.* 2007). Typical processes require one or more of the different types of flexibility: customization, variety, volume (Krajewski *et al.* 2007; Slack *et al.* 2007), and delivery flexibility (Slack *et al.* 2007).

e) **Cost:** is a key objective for companies, especially for those playing in price-driven markets (Slack *et al.* 2007). Low-cost operations produce products at the minimum possible cost to the satisfaction of the customers (Krajewski *et al.* 2007). External changes, such as pressures for price reductions, might affect profit margins in companies with non-resilient cost structures. In addition, costs have different cost related factors, including capacity utilization, productivity, and inventories, among others (Ward *et al.* 1998).

3.1.2 Characteristics of Construction

Construction is examined in the following streams: project-based nature, multiple and concurrent projects, dispersed site locations, uniqueness of schemes.

3.1.2.1 Project-based Production System

Construction in the infrastructure sector is managed on a project basis. Koskela and Vrijhoef (2001) characterized construction as having one-of-a-kind production, site production, and temporary project organization. Typically, temporary and non-repetitive projects take along difficulties to production standardization and modularization, and they do not contribute to obtaining gains of scale (Gosling and Naim 2009). The project-based production process in which construction is inserted lacks smooth communication, especially because of the temporary nature of its developments (Koskela and Vrijhoef 2001). This temporary mind-set in construction is reinforced by the repeated reconfiguration of 'project organizations' (Vrijhoef and Koskela 2000), which are reproduced within the same organization. In addition, the choice of project-based production processes influences the levels of autonomy within business.

The aforementioned project organizations present high levels of autonomy, which increases the influence of project managers. Gaddis (1959) defined a project as an organizational unit dedicated to accomplish a specific goal by considering time, cost, and quality aspects. Gaddis (1959) also emphasizes that project management should be done by combining control and performance with autonomous management for a given project. Koskela and Vrijhoef (2001) emphasized that site production is a specific condition of project-based systems, which in this case is represented by a fixed-position layout. Site production is not an exclusive feature of construction, and it can be found in other businesses such as heavy equipment, among others. Site production and a fixed-position layout require converging logistics, a characteristic widely found in construction companies (Koskela and Vrijhoef 2001), and production environments adopting an engineer-to-order production strategy (Luhtala *et al.* 1994). Deriving from the project-based approach adopted by construction, one can identify two distinct managerial levels: business and project. Business level, also named in this research as enterprise or corporate levels, corresponds to the firm. On the other hand, project level is the level in which each project is undertaken. Different authors recognize the existence of distinct managerial levels in construction (Koskela and Vrijhoef 2001; Formoso and Revelo 1999) and in operations management (Joshi *et al.* 2003).

3.1.2.2 Multiple and Concurrent Projects

As discussed before, the nature of construction companies is to have multiple projects. Such projects are managed autonomously by project managers. However, by having multiple projects such construction companies also have concurrent projects, which produce significant implications. Payne (1995) highlights a number of implications in managing concurrent projects, which this author classifies in five categories:

a) **Capacity** relates to the conflicts regarding the provision of resources, the controls used, and the management approaches applied (Payne 1995). Archer and Ghasemzadeh (2004) highlight that managing multiple projects is typically complex, once resources are scarce in general. Therefore, the first challenge in managing concurrent projects is to balance their demand for accessing an enterprise's resources. Payne (1995) affirms that it is very rare when the demand and availability of resources (i.e. cranes, heavy vehicles) is balanced.

b) **Complexity** recounts to the interfaces between projects, the projects and the organization, and other parties concerned (Payne 1995). The existence of multiple interfaces increases complexity in managing concurrent projects. In order to manage such a complex scenario, the creation of a central capacity planner is recommended for optimizing the utilization of resources, development of activities, and to accommodate changes as they happen (Payne 1995). Scheinberg and Stretton (1994) point out that managing multiple projects is not a simple task, and that traditional methods for doing so (i.e. one-line method, network method) are not as efficient as they should be.

c) **Conflict** is the category that encompasses three types of issues: people, systems, and organizational (Payne 1995). These issues refer to different and unexpected behaviours, which produce unstable relationships in the multi-project environment (Payne 1995). Munns and Bjeirmi (1996) reinforce the idea that conflicts affect the ability to achieve project goals. Due to the temporary nature of projects, Gaddis (1959) affirms that it is hard to manage human resources in a project environment, once people look for future assignments as the current project will come to an end.

d) **Commitment** is directly related to the way people, working on or providing resources, commit to individual projects, and consequently to a number of integrated projects (Payne 1995). Somehow, the level of commitment varies from one project to the other. Munns and Bjeirmi (1996) pointed out lack of commitment is one of the key problems affecting a project's success.

e) **Context** is pointed out by Payne (1995) as the setting of projects (i.e. culture, procedures) or issues related to people, to systems, or to the organization itself. Another factor that reportedly influences the success of a determined project is its context, as pointed out by (Munns and Bjeirmi 1996).

3.1.2.3 Dispersed Site Locations

According to Grimsey and Lewis (2002) infrastructure "is easier to recognize than define", and it is mainly represented by the following key areas: energy, transport, water, telecommunications, and social developments. Infrastructure projects have impacts on daily life, once they reach wider areas and communities. It also should be added that infrastructure projects are generally dispersed over the territory, sometimes in remote locations (Souza and Koskela 2014).

The intrinsic implication of remote locations and site construction is the need for converging logistics. According to Luhtala *et al.* (1994), logistics is about managing flows regardless of the industry. Converging logistics requires the direction of all materials to the construction site where the 'construction factory' is located (Vrijhoef and Koskela 2000). From a control viewpoint, the flow of materials is originated from different supply units, and converge to a common point in the supply chain: the construction site (Luhtala *et al.* 1994). In addition, the fabrication of special materials and components is subject to the customer's order, which contains the unique specifications regarding the project (Luhtala *et al.* 1994).

There are difficulties in coordinating and organizing the flow of materials to a number of dispersed projects, usually located thousands of kilometres from each other. Kovács and Paganelli (2003) highlight that the new production philosophies (i.e. lean/agile manufacturing) and evolving market conditions influence the determination of logistics flows. Such influence refers to the need to reduce inventories and to supply materials just-in-time, no matter where the project is located. Clearly, these objectives are harder to achieve in dispersed and remote site locations.

3.1.2.4 Uniqueness of Schemes

The characteristics of construction projects in the infrastructure projects are unique. Eastman *et al.* (2011) indicate the construction of complex infrastructure projects requires customized components, typically manufactured according to an engineer-to-order (ETO) production strategy. Such components involve structural steel, precast concrete structures, architectural façades, curtain walls of various types, mechanical, electrical and plumbing (MEP) systems, timber roof trusses, and reinforced concrete tilt-up panels (Eastman *et al.* 2011). In this context, construction supply chains present themselves as having not only standardized materials, but also special and one-of-a-kind modules.

ETO companies are usually involved with design, manufacturing and construction of capital projects (Hicks *et al.* 2000). Such companies are characterized by their production features, presenting high levels of customization and several levels in their production structure. Usually, design and project capabilities are considered essential competitive advantages in such companies. In general, ETO companies are formed by the following basic processes:

a) **Design:** This process is concerned with the conceptualization of the product, the description of the specifications and requirements, the simulation of operation and performance, and the definition of design characteristics that will facilitate the following processes (Krajewski *et al.* 2007).

b) **Project management:** This process is related to the definition of policies, guidelines, and a management structure to deliver the project according to its design. Such an approach must consider constraints in terms of time, quality, cost, human resources, among others (Krajewski *et al.* 2007).

c) **Manufacturing:** This process is focused on the production of the products, according to their characteristics. In a typical ETO production strategy, the most common production processes are job and small batch (Krajewski *et al.* 2007).

d) **Assembly:** This process is related to the pre-fabrication and pre-assembly of modules to be used in the construction and commissioning process (Krajewski *et al.* 2007). The efficiency of this process and its real contribution to the performance of the overall ETO production strategy is determined by the design process, as modularization might be part of a mass-customization strategy (da Silveira *et al.* 2001).

e) **Construction and commissioning:** This process is usually performed at the site in which the product will remain. The construction process is concerned with assembling the pre-fabricated modules according to project specifications. The commissioning process is concerned with adjusting and testing the equipment in order to produce its products in pre-defined capacity, efficiency and quality (Krajewski *et al.* 2007).

Managing and purchasing materials for ETO projects present an intrinsic difficulty, once materials are required specifically for one project, and therefore they may not be purchased again in the future. ETO production strategy produces one-of-a-kind, also named as unique, products and this production strategy has been closely related with the construction sector (Gosling *et al.* 2013a). Hicks *et al.* (2001) reported that ETO supply chains have changed over the last years, shifting from specific items to turnkey contracts and through life solutions.

ETO companies tend to have high levels of vertical integration, although activities related to assembling and commissioning are usually outsourced to specialized contractors. Hicks *et al.* (2000) argue that a high level of customization leads to increased costs, higher risks, and long lead times. In the ETO environment, although projects are customized and produced in low volumes, many of their components are purchased in medium and high volumes to supply multiple projects and obtain gains of scale. This type of complexity in the ETO sector makes outsourcing more difficult as product and components specifications are only delivered after the conclusion of the design process.

Hicks *et al.* (2000) also argue that most of the companies have recognised the aforementioned difficulties and are putting efforts into mass-customization strategies in order to reduce uncertainties and attend to the customer's requirements simultaneously. Olhager and Ostlund (1990) have discussed a push-pull production approach, in order to link corporate strategy and its implications in production. In this research, the push-pull system has contributed to increasing a company's competitiveness. Such competitive improvement has been achieved by increasing lead times reliability. Olhager and Ostlund (1990) indicate the development of a better understanding between production and customer involvement positioned at the order point, which is discussed in the next section.

3.1.3 Summary and Critique

Companies should manufacture their products using the most appropriate production process in order to achieve operational efficiency. The different production processes are influenced by a number of variables: volume of production, the variety of products and the level of a product's customization required by their clients, the sequence of production tasks to be performed, the nature of the flows, and the degree of repeatability of work, among others.

By choosing the right process, companies should understand and implement the most suitable production strategy for them. Such strategies are influenced by the above-mentioned variables. However, two additional factors also influence production strategies: the degree of involvement of the suppliers in the specification of the product and the availability of information regarding the demand patterns of products.

Once the correct production process is selected and the right strategy implemented, the company should understand the positioning of its OPP. Each production strategy directs the OPP to be positioned at a different production stage, which generates significant impacts both in internal and in external (i.e. supply chain) operations. By understanding the position of its OPP, the company will be able to fine-tune its production strategy, and consequently its production process, in order to respond appropriately to both the customers and suppliers. The link concerning corporate strategy and operations should be built-up. Such a link will support the internal organization's alignment from both top-down (strategic) and bottom-up (operational) perspectives. In this sense, companies should evaluate in what processes and to what level the five basic priorities (i.e. cost, speed, dependability, flexibility, cost) should be prioritized and monitored in order to guide their path towards increased competitive advantage.

Research in operations management has initially concentrated its efforts in mass production. Developments in high volume production processes (i.e. continuous flow, line, and large batch) were notable during the early years of production management. As discussed before, such processes are closely related to the make-to-stock production strategy, which mainly relies on demand forecast for production planning. However, customers evolved and their requirements evolved as well. In this context, more customized products began to be highly demanded in markets. In this sense, low volume processes and production strategies in the manufacturing sector started to be investigated. Such investigation enabled a series of developments in the particular field of the assemble-to-order and make-to-order production strategies. In this context, attention was raised due to the positioning of the OPP and its influence in production and supply chain planning. However, the development of better low volume processes, the correct understanding of the engineer-to-order production strategy, and the implications of the OPP took a long time to be discussed outside the manufacturing sector. In the construction sector for example, this discussion is much more recent and the application of the aforementioned concepts is still in debate.

By looking at the previously presented general characteristics of production, one can identify that construction is mainly based on two types of processes: small batch and job. These processes present more adherences to construction due to its intermittent flow, low volume of production, customized products, and its unique sequence of tasks. Special, unique, and one-of-a-kind are expressions used to determine the nature of some construction developments, especially those related to the infrastructure sector.

Gosling *et al.* (2012) described Engineer-to-Order (ETO) projects as having high levels of customization, typically managed on a project basis, and directed to construction, capital goods, and shipbuilding sectors. Based on such a definition, one can understand that construction companies building infrastructure developments should adopt an engineer-to-order production strategy. In this sense, construction has generally an early OPP, which is positioned at the design stage of production: works are only started after an order is placed (or a contract is signed) by the owner.

Infrastructure developments are highly customized and their future demand is not predictable. Construction companies have tried to adapt to this circumstance by managing the pipeline of future projects. Although such projects are engineered to order, when they are positioned in a pipeline it is easier to determine their similarities and plan activities ahead. It is worth mentioning that the competitive agenda of construction has slightly evolved over recent years. It is still a consensus that cost, speed, and quality are the key competitive priorities in the sector. However, there is a lack of attention regarding other relevant items regarding competitiveness such as dependability and, more importantly, flexibility.

General characteristics of construction in the infrastructure sector are summarized in Table 4.

Table 4 – General characteristics of construction

Characteristics of Construction	Salient Points	Key References
Project-based production system	Temporary mind-set Autonomous units of production The role of project managers Fixed-position layout Two managerial levels Converging logistics	Gaddis (1959), Luhtala *et al.* (1994), Formoso and Revelo (1999), Vrijhoef and Koskela (2000), Koskela and Vrijhoef (2001), Joshi *et al.* (2003), Gosling and Naim (2009)
Multiple and concurrent projects	Limited capacity Increased complexity Amplified level of conflict Poor commitment Particular context Limited benchmarking Limited exploitation of synergies	Scheinberg and Stretton (1994), Payne (1995), Munns and Bjeirmi (1996), Hobday (2000), Archer and Ghasemzadeh (2004), Luu *et al.* (2008)
Dispersed site locations	Common needs of communities everywhere (i.e. energy, water, transport) Remote locations Site construction Complex logistics	Luhtala *et al.* (1994), Vrijhoef and Koskela (2000), Grimsey and Lewis (2002), Kovács and Paganelli (2003), Souza and Koskela (2014)
Uniqueness of schemes	Highly customized Specific materials and components Highly specialized subcontractors Wide scope of work (design, project management, manufacturing, assembly, and construction and commissioning Long lead times	Olhager and Ostlund (1990), Hicks *et al.* (2000), da Silveira *et al.* (2001), Hicks *et al.* (2001), Krajewski *et al.* (2007), Eastman *et al.* (2011), Gosling *et al.* (2013a)

3.2 Supply Chain Management in Production and Construction

First, the concept of supply chain management is considered. Second, the most popular and well-accepted frameworks for managing supply chains are studied in detail. Third, a set of best practices in supply chain management are revised. Finally, characteristics of construction supply chains are investigated and summarized.

3.2.1 The Concept of Supply Chain Management

The development of the competitive advantage cannot be promoted by a single company itself. The development of the competitive advantage is strongly based on the idea that organizations interact with each other in procuring, designing, producing, marketing, and delivering their products (Porter 2004). The composition of such activities and their performance contributes directly to the company's cost position and its market differentiation (Porter 2004).

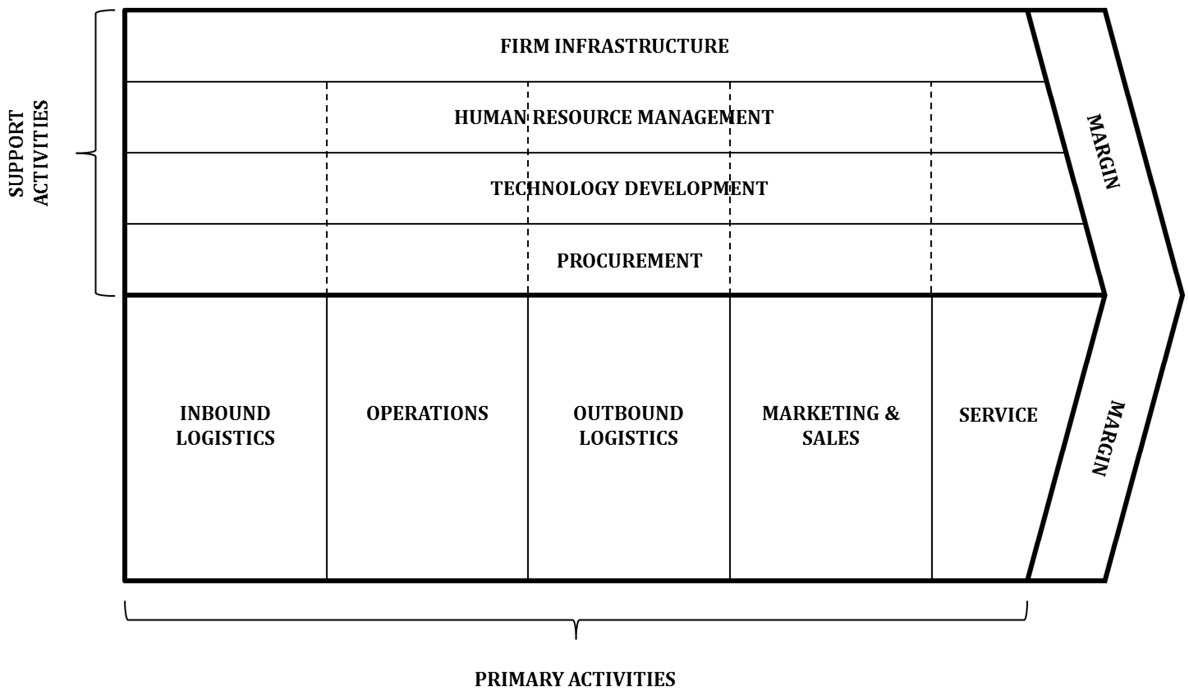


Figure 11 – The generic value chain (Porter 2004)

The idea of a value chain proposed by Porter (2004) has been discussed in many publications investigating the production arrangements (Gereffi 2001; Raikes *et al.* 2000; Kaplinsky and Morris 2003; Kaplinsky 2010) as a comprehensive approach to understand the dynamics between organizations. Porter (2004) defined primary and support activities, which vary in the different organizations and depend on the particularities of the business' processes and the firm's strategy. According to this proposition, the Value Chain might be described as a theory of the firm (extended to its suppliers and customers) that views the organization as a collection of inter-related production functions, considering them as activities (Porter 2004), shown in Figure 11.

There are two groups of activities according to Porter (2004) :

a) **Primary activities:** five generic categories of primary activities have been defined in order to provide the basis for competition in any industry. Each category, namely inbound logistics, operations, outbound logistics, marketing and sales, and service might be divided into a variety of distinct activities according to the firm's strategy.

b) **Support activities:** four generic categories of support activities have been drawn in the Value Chain model. Each category, namely procurement, technology development, human resource management, and the firm's infrastructure might also be divided in a variety of different activities according to each company.

Faße *et al.* (2009) have highlighted the Value Chain model as focused on industrial firms, and by breaking down their activities such industrial firms are able to build-up value added activities and seek for competitive advantage. On the other hand, the value chain proposition is restricted to the production processes at the firm level (Faße *et al.* 2009).

Kaplinsky and Morris (2000) have stated two major contributions in the Value Chain model, namely the (i) separation of the different functions in a firm (process of supply, transformation, and support services) and (ii) the conceptualization of value systems. By separating the different functions the Value Chain model focuses not only in the physical transformation but also in the business processes (Kaplinsky and Morris 2000).

Ellram and Cooper (1990) discussed the idea of Supply Chain Management (SCM) as a synthesis of three important trends and trading practices from operations and strategic management. Firstly, SCM deals with balancing inventory not only within a single company but also in the many tiers of the supply chain. Secondly, SCM points towards integration of the many tiers of supply chain based on information technology in order to reduce uncertainty. Thirdly, SCM requires a specific approach to manage competitiveness, changing from an adversarial perspective to a cooperative approach.

Cooper *et al.* (1997) present the supply chain as a sequence of determined processes that integrates different companies in terms of their material and information flow. In this context, these authors discuss supply chain management in terms of management components, business processes, and structures.

Simchi-Levi *et al.* (2000) define supply chain management as a set of approaches applied to integrate suppliers, manufacturers, warehouses, and stores, in order to produce and distribute products at the right quantities, in the right locations, and at the right time, respecting service level and lowering costs. In addition, these authors underscore the need for a structured framework for designing, operating and improving the aforementioned approaches.

Chopra and Meindl (2007) present supply chain management as a set of decisions involving design, planning, and operation in a multi-organizational environment. In addition, these authors discuss that SCM has a push/pull view regarding its processes and the relations between the many tiers of the supply chain. A push/pull view of SCM deals with a categorization of the processes based on whether they are initiated in response to a customer order or in anticipation of a customer order.

Krajewski *et al.* (2007) present supply chain management as a strategy to organize, control, and motivate the resources involved in the flow of information and materials within a multi-organizational process. These authors highlight the relevance of integration as a competitive weapon in SCM and discuss internal (engineering changes, new product introduction, product promotions, information errors) and external causes (volume changes, service and product mix changes, late deliveries) involved in supply chain dynamics.

Schniederjans *et al.* (2010) present supply chain management as the coordination of supply chain partners to achieve the objectives of a business firm. Such objectives may include cost reduction, adding value to the product or service, and maintaining a quick response, among others. Gosling *et al.* (2012) stated that different supply chains require contextualized management approaches due to their particular uncertainty profiles. Such a proposition indicates the correlation between product characteristic, production strategy, and SCM approach. Thus, not only generic management functions and elements should be incorporated in SCM frameworks, but also particular elements for its deployment. According to Estampe *et al.* (2013), supply chain management is defined at the strategic level of a company, and aims at coordinating operational tasks within a chain. In this context, supply chain management ranges from strategy to operations, and therefore different managerial levels are required.

The aforementioned views lead to several observations regarding supply chain management. Such views summarize research developments of different researchers at the time, and their perceptions show the evolution of SCM, from a logistics approach to a multi-organizational complex process. In addition, the evolution of SCM should be discussed not only in terms of operation and control, but also in terms of design and improvement. Design, operation and control, and improvement form the basis of the production template (Koskela 2000).

First, supply chain management has evolved from the traditional approach of logistics management to a multi-organizational perspective. A multi-organizational environment requires specific concerns regarding the different levels of management maturity of different companies, their diverse level of trust within their supply chains, and their variety of approaches for management. Thus, the design of supply chain management must consider strategic and governance issues concerned about the different tiers of the supply chain. In this context, Roehrich and Lewis (2010) have discussed a conceptual model for a complex inter-organizational system based on contractual and relational levels of governance.

Second, supply chain management developed a need for flexibility as a key competitive priority. The initial developments of operations management have focused on cost reduction and optimization throughout the supply chain. Later, quality has become the most important issue in order to meet the market requirements. In recent years, research has focused on flexibility as a key competitive issue in operations. Simchi-Levi (2010) affirmed that operations strategies should be aligned with the product categorization, meaning that different products require diverse strategies in terms of operations and, consequently, in terms of their supply chain management model.

Third, the relevance of supply chain management has increased in the business scenario. Companies have become global and have started to sell products and deliver services in all continents. In this sense, the management of the flow of information and material has also become critical. Such an environment has evolved from inventory control and demand forecasting to a more holistic approach, based on the conceptual view of a production process. A production process is usually described in terms of its design, operation and improvement. In the same context, supply chain management might be described in the same manner. Vachon *et al.* (2009) maintain that interaction between suppliers is the key issue to align competitive priorities within a supply chain. Such discussion regarding competitive priorities also refers to an organizational view of supply chain management related to production process.

The different views about supply chain management have led research towards many different directions, as synthesised in Table 5. Such evolution is presented based on the perspective of different authors regarding design, operation, and improvement of the SCM process. Nonetheless, it is worth mentioning that SCM research has not evolved at the same pace for all production strategies. Traditionally, SCM has been designed aiming at industries focused on increased product volumes, decreased levels of customization, and production planning driven by demand forecasts.

Table 5 – Different views regarding supply chain management

	Design	Operation and Control	Improvement
Ellram and Cooper (1990)	Issues as partnerships and third-party relationships are discussed in this paper. These authors investigate and categorize the different roles within a supply chain. The paper also discusses the risks of partnerships in terms of economic, managerial, and strategic issues.	N/A	The study of cooperation and collaboration within the supply chain is presented as a key issue to increase efficiency and improve performance. Nevertheless, these authors argue that achieving high levels of integration is extremely difficult in practice.
Cooper *et al.* (1997)	A discussion about integration is placed in design. These authors suggest that the supply chain is an inter-organizational process, aiming at an overall optimization. In a strategic sense, this discussion shifts the paradigm from a local optimized strategy towards an integrated and effective global performance.	The differences between logistics and supply chain management are positioned in this study. In this context, these authors highlight that the operation of logistics processes constitute the basis of supply chains at operational level. Logistics processes are usually grouped under three basic dimensions, namely procurement, production, and distribution.	A framework for supply chain management is presented. Such a framework comprises business processes, supply chain structures, and management components. The feedback provided by the processes is assessed by metrics, and such measures provide the basis for further improvement plans.
Simchi-Levi *et al.* (2000)	A conceptualization regarding supply chain management design is placed in terms of building strategic alliances and long-term relationships. In addition, it highlights the implications of design in operation and improvement within the SC environment.	Tools and techniques are presented for managing logistics. Such techniques are discussed in terms of inventory, demand, warehouse management, information technology, among others.	A brief discussion about supply chain metrics is placed. The most common measures are presented and supply chain benchmarking is introduced.
Schniederhans *et al.* (2010)	The interface between lean principles and supply chain management is studied. Topics such as leadership, growth, customer value, ethics, trust based alliances, among others, are presented as key features for designing supply chain management.	Operation is discussed in terms of demand pulling and synchronization. In addition, the conceptualization of supply chain is investigated in terms of lean and agility. Flow maximization is also introduced.	These authors propose an approach based on continuous improvement and waste elimination. Such an approach is aligned with the lean philosophy for improvement.
Gosling *et al.* (2012)	A criticism about the one-size-fits-all approach for managing supply chains is placed. These authors argue that different business operations require diverse SCM structures. Flexibility is presented as a key strategic issue in SCM.	N/A	Uncertainty elimination is raised as a crucial point for improvement. These authors present that uncertainties must be identified, analysed, ranked, categorized, and eliminated in order to provide a basis for improvement.

3.2.2 Frameworks for Supply Chain Management

Davenport and Short (1990) presented ideas regarding the recent transformation in organizations based on Information Technology (IT) achievements and Business Process Reengineering (BPR). BPR has been referred to as the analysis, design, and redesign of work flows within and between organizations (Davenport and Short 1990). Nevertheless, a more direct definition defined business process as how an organization performs its work internally or externally in order to achieve a determined objective (Davenport 2005). Davenport and Short (1990) defined two important characteristics for business processes. First, business processes have defined outcomes for their customers even though the customers are internal or external. Second, business processes have the capability of crossing organizational boundaries. In their seminal paper, Davenport and Short (1990) proposed a set of five steps for process redesign and a set of recommendations for implementing, managing, and improving process. On the one hand, the first steps for process redesign have been named as Develop Business Vision and Process Objectives, Identify Processes to be Redesigned, Understand and Measure Existing Processes, Identify IT Levers, and Design and Build a Prototype of the Process (Davenport and Short 1990). Such steps have been deeply detailed which provided significant directions for organizations to deal with process redesign. On the other hand, the definition of management roles supported continuous improvement. Davenport and Short (1990) reported that many organizations have implemented cross-functional teams sponsored by senior executives in order to assure the shift from a functional management perspective to a process-oriented perspective. In addition, Davenport and Short (1990) have related continuous improvement of business processes to the earlier developments of the quality movement. In this context, a process requires first its stabilization and afterwards its improvement.

The integration and management of a network of companies has been described as a broad and challenging task (Lambert *et al.* 2005). In addition, Lambert *et al.* (2005) presented that business processes should be used as a structure to manage activities between the members of a supply chain. In the literature, there are different approaches (Cooper *et al.* 1997; Melnyk *et al.* 2000; Mentzer *et al.* 2001; Srivastava *et al.* 1999; Stewart 1997) for managing supply chains based on a process-oriented perspective.

The first developments of process-oriented frameworks for supply chain management were started in the early 1990s. The SCOR model has been presented as the first cross-industry framework for SCM, and in the first version the model had four major processes: Plan, Source, Make, and Deliver (Stewart 1997). The GSCF model has been presented based on a set of three elements defining supply chain network structures, business processes chains, and management components, (Cooper *et al.* 1997).

Later, Srivastava *et al.* (1999) proposed a framework based on three major business processes, namely product development management, supply chain management, and customer relationship management. The framework has indicated several sub-processes and a set of drivers for value generation to shareholders linked to each of the three aforementioned business processes. Lambert *et al.* (2005) evaluated that the model has focused on the marketing function and has not addressed issues from other corporate functions.

Melnyk *et al.* (2000) have presented a framework composed of eight business processes, namely plan, acquire, make, deliver, product design/redesign, capacity management, process design/redesign, and measurement. Lambert *et al.* (2005) reported that such framework has been based on three contexts: operational, planning and control, and behavioural. In addition, Lambert *et al.* (2005) reported a resemblance between SCOR business processes and four of the eight proposed processes by Melnyk *et al.* (2000). Further details of the aforementioned eight business processes are not provided.

Mentzer *et al.* (2001) presented a framework that emphasizes cross-functional interaction between a firm and its supply chain members. Such a framework is illustrated in Figure 12, in which directional supply chain flows (i.e. products, services, financial resources), the traditional business functions (i.e. marketing, sales, research and development, forecasting, production, procurement, logistics, information technology, finance, and customer service), and the critical role of customer value and satisfaction are integrated altogether.

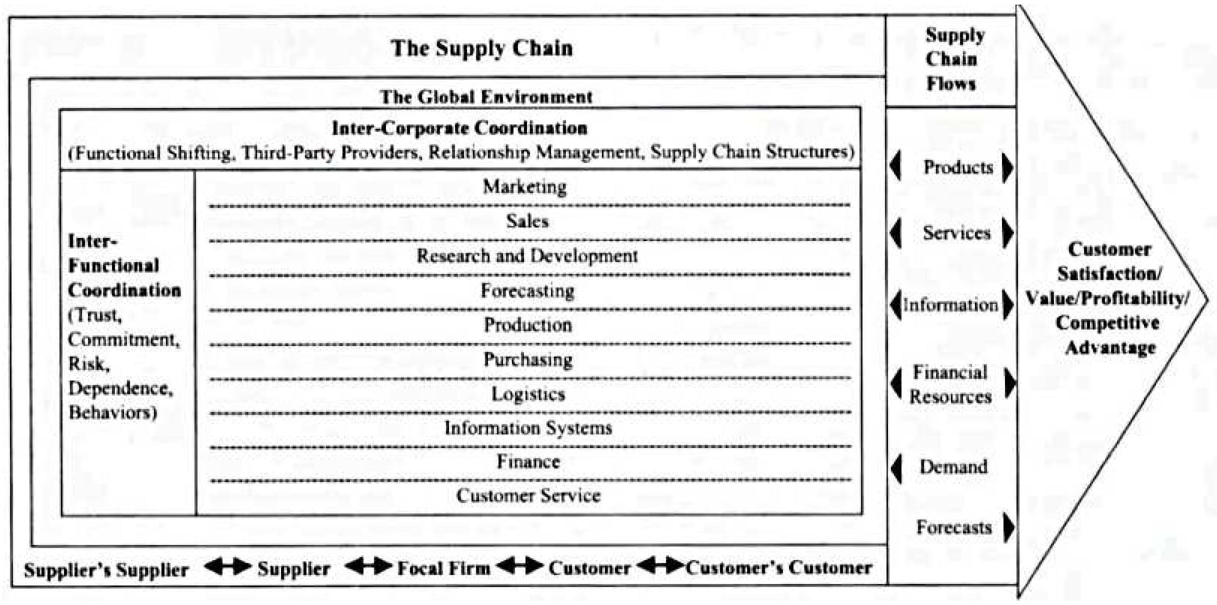


Figure 12 – A model of supply chain management (Mentzer *et al.* 2001)

Lambert *et al.* (2005) reported that the processes that need to be implemented in this framework have not been delineated precisely. In this context, Lambert *et al.* (2005) stated that only SCOR and GSCF frameworks have included business processes that could be used for achieving cross-functional integration. In addition, Lambert *et al.* (2005) have argued that the business processes described in SCOR and GSCF were significantly detailed in the literature, which enables a further comparison between both models. Finally, Lambert *et al.* (2005) positioned that SCOR and GSCF models are based on the implementation of business processes that connect customers and suppliers, and both models are supported by major companies, attesting to their acceptability. Thus, in the following sections SCOR and GSCF models are described in depth, analysed, and compared.

3.2.2.1 Supply Chain Operations Reference (SCOR) Model

The origins of the Supply-Chain Council (SCC) can be retraced to two consulting firms – PRTM and AMR – that supported a set of leading companies to move to process-based management and to increase their supply chain management performance in the early 1990s (Stewart 1997). This group of companies, together with other US and multi-national firms, formed the Supply-Chain Council in 1996, an independent organization designed as an initiative to develop a supply chain implementation model (Bolstorff and Rosenbaum 2003). At the beginning, the SCC efforts integrated 69 world leading companies (Lambert *et al.* 2005), and by 2002 SCC had acquired more than 750 members worldwide (Bolstorff and Rosenbaum 2003). The output of the initial efforts of the SCC resulted in the proposition of the first version of the Supply-chain Operations Reference (SCOR) model in early 1997. SCOR has been recognized as the first cross-industry framework for integrated supply chain management (Stewart 1997). Presently, the SCOR model is in its 11th version.

The focus of the SCOR model is centred on the supply chain management function and its interactions with customers and with physical and market transactions. SCOR has been developed for evaluating and improving enterprise-wide supply chain performance and management by providing standard process definitions, terminology, and metrics (Stewart 1997). According to Stewart (1997) the model has been released by the SCC to represent the industry standard for describing and improving operational process effectiveness. Bolstorff and Rosenbaum (2003) affirm that SCOR combines elements of business process engineering, benchmarking, and leading practices into a single framework. Nevertheless, it is noteworthy that the SCOR model has an operational process perspective (Zhou *et al.* 2011).

Huan *et al.* (2004) pointed out that the major objective of the SCOR model is to provide and improve alignment between the marketplace and the response of a supply chain. Such an objective is based on the premise that the better the alignment, the better the bottom-line performance. Zhou *et al.* (2011) highlighted that the benefits of implementing SCOR includes faster cycle times, less inventories, improved visibility of the supply chain, and access to important customer information.

3.2.2.1.1 SCOR Overview

Supply chain management is defined as an integrated set of processes in the SCOR model, composed of Plan, Source, Make, Deliver (Stewart 1997) and Return (Bolstorff and Rosenbaum 2003; Lockamy III and McCormack 2004; Zhou *et al.* 2011) from the supplier's supplier to the customer's customer. The design of the SCOR model has been deployed to communicate, compare, and develop new or improved supply chain practices (Stewart 1997).

In addition, the basic process defines the processes that encompass the supply chain, and extend across all parts of the manufacturing and delivery process forming a process-centred view of supply chain management (Stewart 1997). According to Lambert *et al.*

(2005) each process is analysed and implemented around two components: Business Process Reengineering (BPR) and best practices analysis. The following five basic processes are described below:

a) **Plan:** deals with supply resources, demand aggregation, inventory and capacity planning, and rough-cut capacity for all products and all channels (Bolstorff and Rosenbaum 2003). Zhou *et al.* (2011) affirm that supply chain planning process uses information from external and internal operations to balance aggregate demand and supply and has the ability to get real-time information and rebalance supply chains using online information. Stewart (1997) has also included the Plan infrastructure aspects in terms of make/buy decisions, supply-chain configuration, business planning, manufacturing ramp-up, and end-of-life management, among others. Finally, Zhou *et al.* (2011) suggest that, based on the literature, functional coordination within a firm is a relevant topic in the supply chain planning agenda "because the alignment between the functions is necessary to achieve a firm's strategic goals".
b) **Source:** material acquisition has a set of activities such as obtain, receive, inspect, hold, and authorize payment for raw materials and purchased finished goods (Stewart 1997; Bolstorff and Rosenbaum 2003). In addition, Stewart (1997) has indicated Source infrastructure aspects such as vendor certification and feedback, sourcing quality, inbound freight, component engineering, vendor contracts, and initiation of vendor payment. Zhou *et al.* (2011) affirm that sourcing practices connect manufacturers with suppliers and these authors listed a set of best-practices for buyer-supplier relationship: (i) establishing a long-term supplier-buyer relationship, (ii) reducing the supplier base, (iii) implementing just-in-time delivery, (iv) providing feedback about suppliers' performance evaluations, and (v) implementing suppliers' development programmes.
c) **Make:** request and receive material, manufacture and test product, package, hold and/or release product are aspects that have been related to production execution (Bolstorff and Rosenbaum 2003; Stewart 1997). Nevertheless, Stewart (1997) has also presented a few aspects for Make infrastructure such as engineering changes, facilities and equipment, production status, production quality, shop scheduling, short-term capacity. Zhou *et al.* (2011) associated with

the Make process the idea of the transformation process in which efficient practices transform raw materials into finished goods. In addition, these authors highlight a set of best practices for the Make process such as just-in-time production, total preventive maintenance, total quality management, and human resource management.

d) **Deliver:** this process has been defined by Stewart (1997) based on demand management, order management, warehouse management, transportation management, installation management, and delivery infrastructure. Bolstorff and Rosenbaum (2003) have included in the Deliver process the following activities, among others: execute order management processes, generate quotations, configure product, create and maintain customer database, maintain product/price database, consolidate orders, ship products, manage transportation processes and import/ export, and verify performance. Zhou *et al.* (2011) showed that delivery has become a critical link in supply chain management. In addition, these authors emphasized a set of capabilities in the Deliver process: real-time information sharing, agility, single contact point for orders consolidation, and information technology enablers (i.e. bar code technology), among others.

e) **Return:** the proposition of the fifth process in the SCOR model has been made in the SCOR version 5.0 according to Lockamy III and McCormack (2004), and this process deals with defective products, warranty, and excess return processing, including authorization, scheduling, inspection, transfer, warranty administration, receiving and verifying defective products, disposition, and replacement (Bolstorff and Rosenbaum 2003).

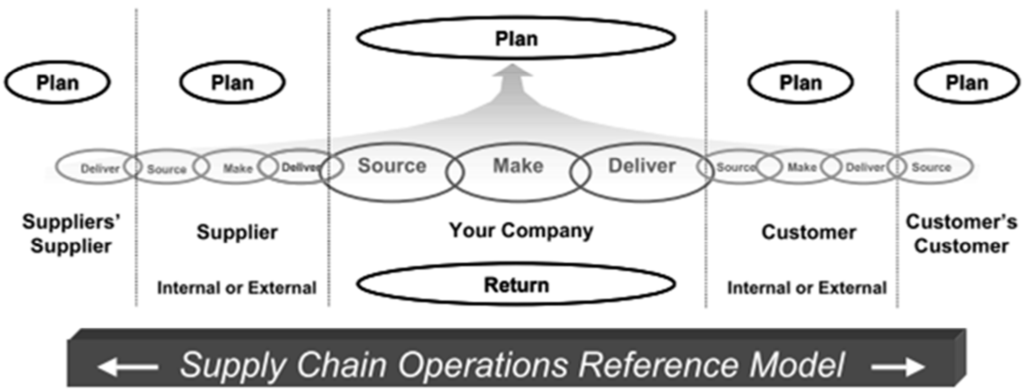


Figure 13 – SCOR framework and its processes (Bolstorff and Rosenbaum 2003)

In Figure 13, the interactions of the different processes and the SCOR model are positioned in the supply chain. According to Bolstorff and Rosenbaum (2003) and Stewart (1997) the span of SCOR covers all customers interactions from order entry through paid invoice, all physical material transactions from the supplier's supplier to the customer's customer including field service logistics, and all market interactions from the understanding of aggregate demand to the fulfilment of each order.

In addition, Stewart (1997) stated that the key components of the SCOR model are the delivery of standard descriptions of the process elements that compose complex management processes, the provision of benchmark metrics used to compare process performance to external points of reference, the description of best-in-class management practices, and the mapping of software products that enable best practices.

Lockamy III and McCormack (2004) and Stewart (1997) have stated that the SCOR model has been developed in order to provide the basis for the implementation of a process-based approach to supply chain management. Such a process-based approach enables internal and external supply chain organization, uses benchmark and best practice data for prioritization of improvement activities, identifies information technology solutions in order to increase integration within the supply chain, and measures on-going process improvements and fine-tune efforts as needed (Stewart 1997).

The different levels of the SCOR model are presented below:

- **a) Level 1:** a broad definition of the Plan, Source, Make, Deliver (Stewart 1997) and the Return (Bolstorff and Rosenbaum 2003) processes is provided. In addition, at this level the company establishes its supply chain's competitive objectives (Stewart 1997). Lockamy III and McCormack (2004) linked to Level 1 the definition of the scope and content of the core management processes for Plan, Make, Source, Deliver, and Return.
- **b) Level 2:** a set of 26 core process categories that are possible components of a supply chain is described (Lockamy III and McCormack 2004; Stewart 1997). At this level is defined the configuration of planning and execution processes in material flow, using standard categories like stock, to-order, and engineer-to-order (Bolstorff and Rosenbaum 2003). According to Stewart (1997) a company

can configure both its actual and ideal supply chain by selecting from these core processes.

c) **Level 3:** a detailed process element information for each Level 2 category is presented in order to organize information for planning and setting goals successfully (Lockamy III and McCormack 2004; Stewart 1997). Bolstorff and Rosenbaum (2003) stated that Level 3 defines the business process used to transact sales orders, purchase orders, work orders, return authorizations, replenishment orders, and forecasts.

d) **Level 4:** a broad implementation is conducted and at Level 4 companies put specific supply chain improvements into play (Stewart 1997). This level does not define specific elements in the industry-standard model because Level 4 characteristics are unique to each company (Stewart 1997). Lockamy III and McCormack (2004) argue that at Level 4 firms must implement specific supply chain management practices based on their competitive priorities and business conditions in order to achieve the preferred level of performance.

For improvement, the SCOR model comprises two different supply chain perspectives, one internal and other external:

- On the one hand, internal improvement perspective deals with best practices that are viewed as a means to compete more effectively in a scope that includes immediate supplier to immediate customer (Stewart 1997);
- On the other hand, external improvement aims at resolving partner-related process issues, in which best practices are viewed as the means to improve total supply chain performance, ranging from supplier's supplier to customer's customer in a "chain of chains" (Stewart 1997). In addition to this view, Huan *et al.* (2004) argue that each basic supply chain is a "chain" of Source, Make, and Deliver execution process within the SCOR model.

In Figure 14, the different levels of the SCOR model are presented.

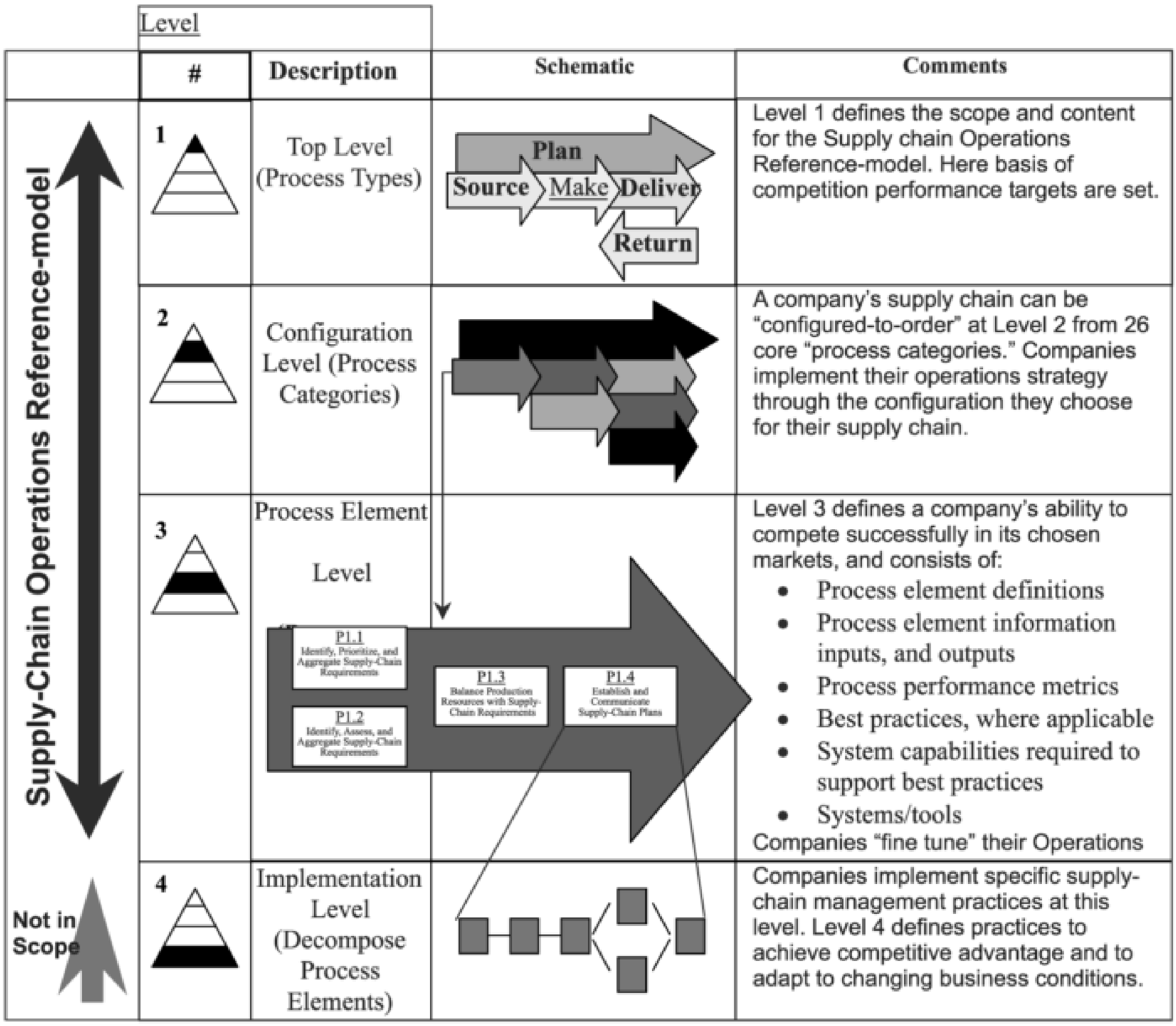


Figure 14 – SCOR framework and its levels (Lockamy III and McCormack 2004)

3.2.2.2 Global Supply Chain Forum (GSCF) Model

The development of the GSCF model has been associated with the emerging research initiatives related to Supply Chain Management (SCM) in the early 1990s. Cooper *et al.* (1997) have stated that a new understanding of operations management is necessary and therefore there is a need for the integration of business operations in the supply chain that goes beyond logistics. In this context, logistics has been presented as an operational aspect and SCM as a strategic function. It appears that supply chain management is logistics taken across inter-organizational boundaries (Cooper *et al.* 1997).

Hewitt (1994) has found three dimensions for redesigning supply chain processes in this context. The first is related to work structure in terms of widening team-based activities, incorporating flexibility and responsiveness requirements for practice design, and providing feedback loops that drive variable activity mix in a mass customization approach. The second is related to information flow in terms of proposing new combinations of data support systems, implementing concurrent rather than sequential decision support, and defining information as a corporate asset. Finally, the third is related to decision authority in terms of focusing on customer decision making, implementing corporate objectives that drive reward systems, and concentrating on the front line for increasing empowerment.

The discussion regarding the conceptualization of the process definition in the supply chain has been discussed in the seminal GSCF paper by Cooper *et al.* (1997). A business process has been defined as a set of reasonably related tasks performed to accomplish a clear business outcome (Davenport and Short 1990). In this context, a broader definition of supply chain process affirms that it can cross organizational boundaries, independently of formal structure (Cooper *et al.* 1997). Hewitt (1994) has reported that the application of BPR for supply chain redesign can lead to breakthrough levels of efficiency and effectiveness not only intra-enterprise but also inter-enterprise. Thus, the application of a process-based approach in a multi-enterprise environment has become necessary. Such necessity has been justified because supply chains comprise a network of multiple businesses and relationships (Lambert *et al.* 1998).

3.2.2.2.1 GSCF Overview

The general structure of the GSCF framework consists of three major and interrelated elements: supply chain structure, business processes, and management components (Cooper *et al.* 1997) as shown in Figure 15. Lambert *et al.* (1998) have stated that the combination of these three elements captures the essence of SCM. Lambert and Cooper (2000) have defined that the supply chain structure comprises the member firms and the links between them, business processes are the activities that produce a determined output to the customer, and the management components are the managerial aspects that integrate the business process and make them connectable and manageable across the supply chain.

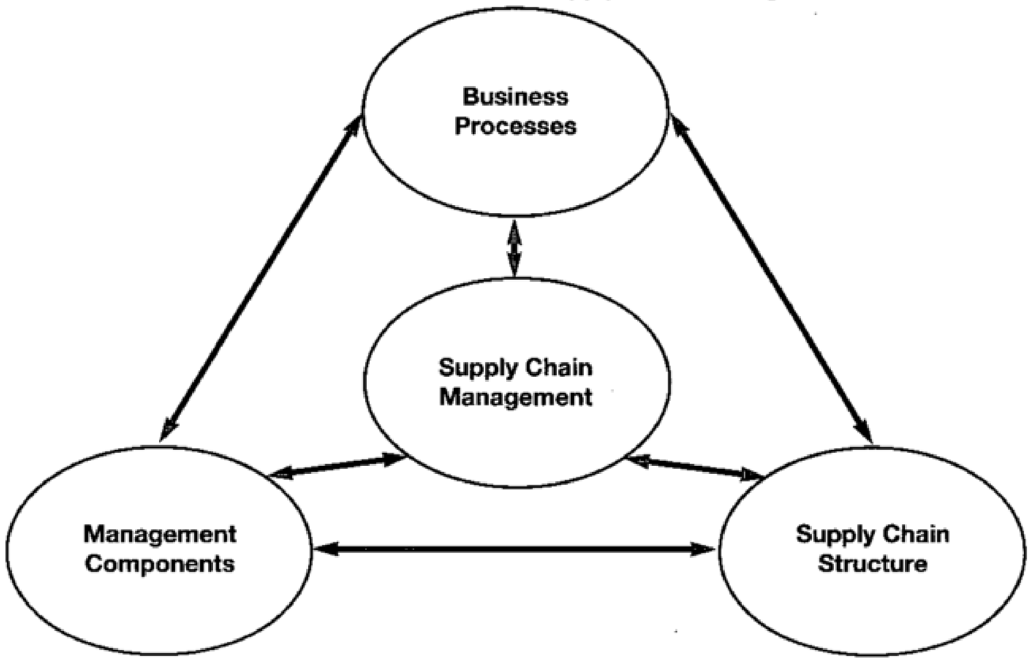


Figure 15 – Framework of supply chain management (Cooper *et al.* 1997)

Lambert *et al.* (1998) introduced three questions to the aforementioned elements. The question addressing the structure of the supply chain is "Who are the key supply chain members with whom to link processes?". The question related to the business processes is "What processes should be linked with each of these key supply chain members?". The question associated with management components is "What level of integration and management should be applied for each process link?".

3.2.2.2.2 Supply Chain Network Structure

An important element of managing the supply chain is the understanding of how the supply chain network structure has been designed (Lambert *et al.* 1998). In addition, there are different factors that affect the structure such as the complexity of the product, the number of available suppliers, and the availability of raw materials (Lambert and Cooper 2000). Nevertheless, it would be rare for a firm to participate in only one supply chain, given that for most manufacturers the supply chain looks like a pipeline (Cooper *et al.* 1997). Thus, the determination of the length of the supply chain and the number of suppliers and customers to be included in the management scope becomes critical.

The list below indicates the features to be considered in the network structure of a supply chain:

a) **Identifying supply chain members:** including all types of members may increase the level of complexity for supply chain management as the number of members from tier level to tier level grows as well (Lambert *et al.* 1998). The integration and management of all process links with all members across the supply chain would be counterproductive, if not impossible (Lambert and Cooper 2000). Cooper *et al.* (1997) affirm that the closeness of the relationship at different points in the supply chain might be different and that more partnership characteristics are exhibited with key suppliers or customers. Lambert and Cooper (2000) stated that determining which members are critical to the success of the company and the supply chain is the key for properly allocating managerial attention and resources. Lambert and Cooper (2000) stated that defining primary and supporting members becomes essential in this context. On the one hand, primary members are those autonomous companies that actually perform operational and/or managerial activities in the business processes in order to produce a specific output for a particular customer or market (Lambert *et al.* 1998). On the other hand, supporting members are those that simply provide resources, utilities, or assets for the primary members of the supply chain (Lambert and Cooper 2000). Nevertheless, the same company can be a primary and a supportive member of the supply chain, or can perform primary activities related to one process and supportive activities related to another process (Lambert *et al.* 1998). Lambert and Cooper (2000) stated that the approach for differentiating between types of members in a supply chain is similar to how Porter (2004) distinguishes between primary and support activities in the Value Chain framework. Lambert *et al.* (1998) mentioned that by defining primary and supporting members enables the definition of the point-of-origin and the point-of-consumption of the supply chain. Lambert and Cooper (2000) defined that the point-of-origin of the supply chain arises where no preceding supplier exists, and suppliers to the point-of-origin are exclusively supporting members. Complementary, the point-of-consumption is where no further value is added, ant the product and/or service is consumed (Lambert *et al.* 1998). Figure 16 shows the supply chain network structure from the perspective of the focal company.

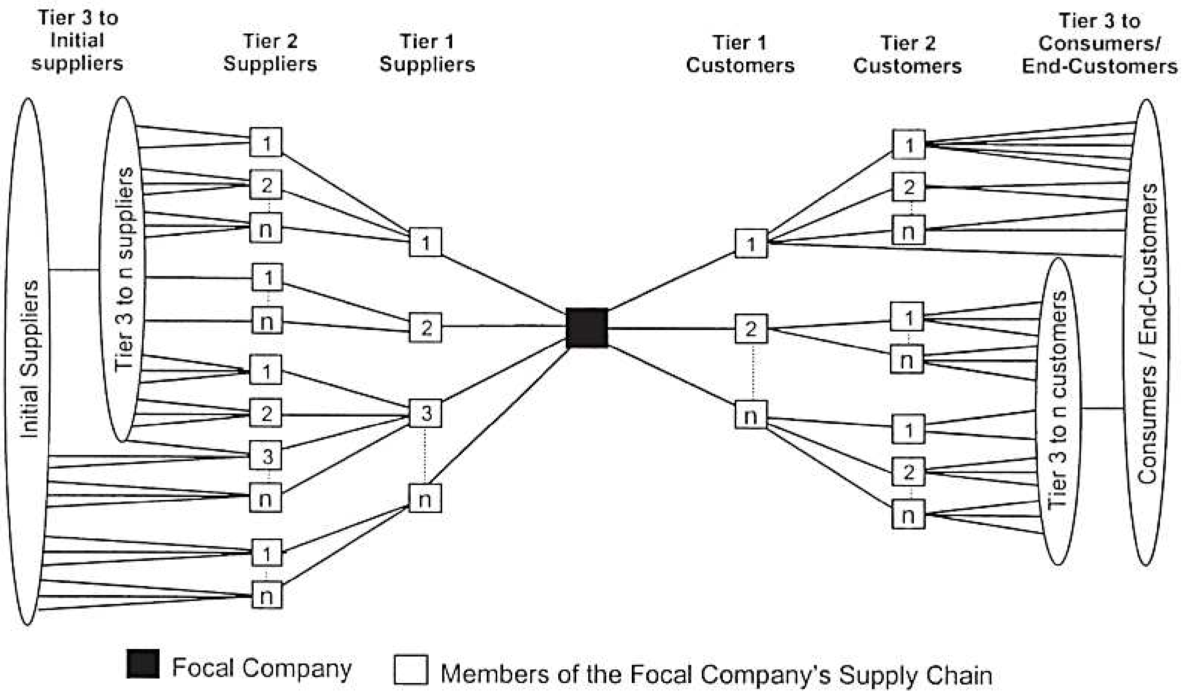


Figure 16 – Supply chain network structure (Lambert and Cooper 2000)

b) The structural dimensions of the network: three structural dimensions are essential for describing, analysing, and managing the supply chain: horizontal structure, the vertical structure, and the horizontal position of the focal company within the end points of the supply chain (Lambert *et al.* 1998). The horizontal structure states the number of tiers across the supply chain, which may be long with numerous tiers or short with few tiers (Lambert and Cooper 2000). The vertical structure raises the number of suppliers or customers within each tier, which can have a narrow structure with a few companies at each tier level or a wide form with many companies at each tier level (Lambert *et al.* 1998). The focal company's horizontal position can be positioned near the initial source of supply, near the ultimate consumer, or somewhere near these end points of the supply chain (Lambert and Cooper 2000). A number of factors might influence the supply chain structure such as outsourcing logistics, manufacturing, marketing, or product development activities (Lambert *et al.* 1998). Such factors may contribute not only to increase the length and width of the supply chain but also to influence the horizontal position of the focal company in the supply chain network (Lambert and Cooper 2000). Lambert *et al.* (1998) have found that focal companies with immediately wide vertical structures may manage only a few tier-2 suppliers or customers by transferring activities (i.e. relocating small customers to distributors further down in the supply chain). Such an approach can be applied to the focal company's network of suppliers or customers (Lambert *et al.* 1998). Lambert and Cooper (2000) reported the studied supply chains looked different from each company's perspective, given that the management of each company perceives its firm as the focal company. Thus, Lambert *et al.* (1998) stated the perceived supply chain network is arbitrary. Nevertheless, because each firm is a member of the other's supply chain, their interrelated roles and perspectives must be clearly understood (Lambert and Cooper 2000). The integrated management of crossing business processes through many different organizations can only be successful if it makes sense for all the companies in the supply chain (Lambert *et al.* 1998).

c) **Types of business process links:** as discussed above, integrating and managing all business process links within the supply chain might be impossible and counterproductive. Lambert *et al.* (1998) have found that some links are more critical than others and have identified four different types of business process links: managed process links, monitored process links, not-managed process links, and non-member process links shown in Figure 17. First, managed process links are links where the focal company collaboratively integrates a process with one or more customers/suppliers, generally at tier 1 (Lambert *et al.* 1998; Lambert and Cooper 2000). Second, monitored process links are not critical links to the focal company but they have to be properly managed between other member companies and they are subject to further audits (Lambert *et al.* 1998; Lambert and Cooper 2000). Third, not-managed process links are links that the focal company is not involved with and are not critical enough to be monitored, giving to the other members full autonomy to manage them correctly (Lambert *et al.* 1998; Lambert and Cooper 2000).

Non-member process links are process links between members of the focal company's supply chain and non-members of the supply chain. Such links are not considered as links of the focal company's supply chain, although they can affect its performance (Lambert *et al.* 1998; Lambert and Cooper 2000). The identification and description of the business process links promote an understanding of how integration may vary away from the first tier (Lambert *et al.* 1998).

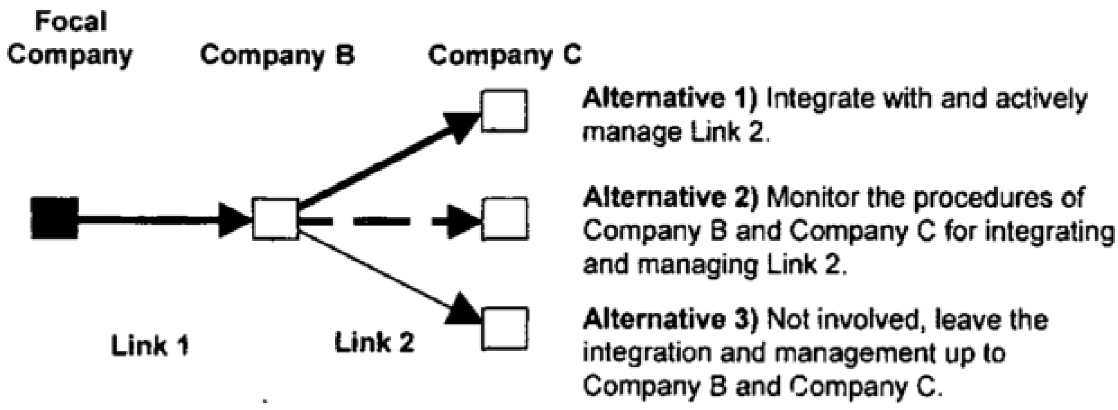


Figure 17 – Alternatives for involvement (Lambert *et al.* 1998)

Lambert *et al.* (1998) reported that in times of shortage companies might discover that it is important to manage their supply chains beyond tier 1 aiming at obtaining better overall performance (Lambert *et al.* 1998). In this context, companies might work through or around different links in order to achieve specific objectives (i.e. product availability, improved quality) (Lambert *et al.* 1998). Lambert *et al.* (1998) highlighted that monitored and non-member types of process links have not received previous attention from the literature. Nevertheless, they might be incorporated when analysing the diversity of possible forms of supply chain integration (Lambert *et al.* 1998) as shown in Figure 18.

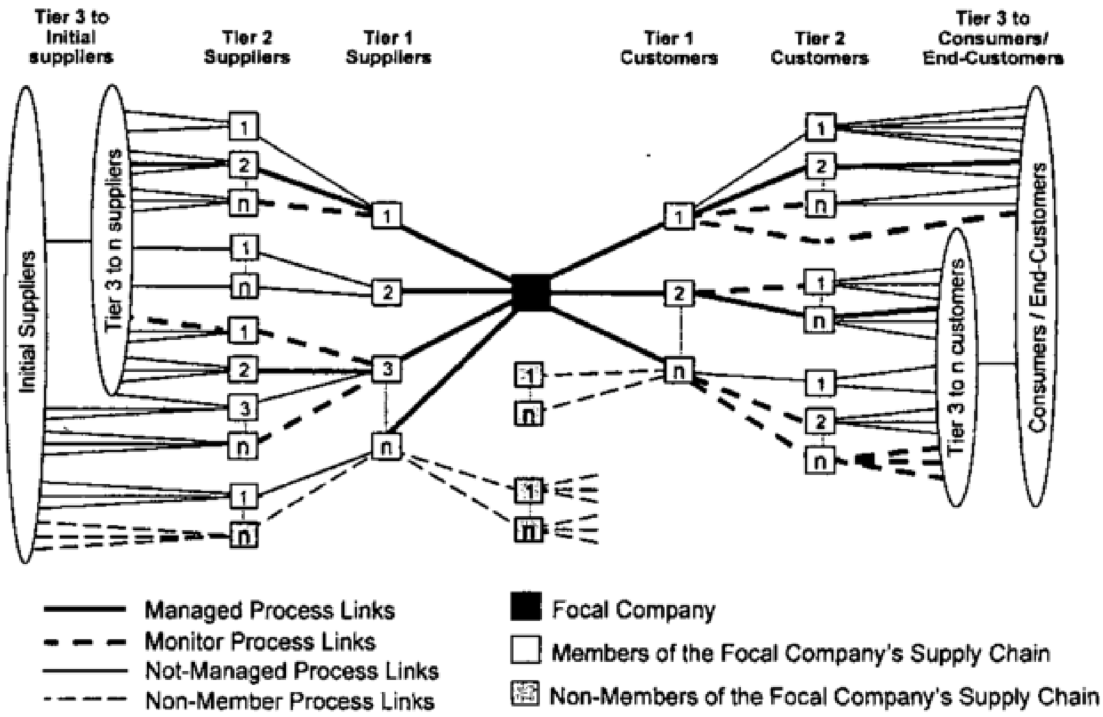


Figure 18 – Types of inter-company business process links (Lambert *et al.* 1998)

3.2.2.2.3 Business Processes Chains

Lambert *et al.* (1998) reported a lack of inter-company consistency in process management due to a variety of reasons such as different activity structures, number of processes, activities, and labels. It is also reported that such inconsistency causes significant friction and inefficiencies in supply chain management (Lambert and Cooper 2000). Thus, the primary focus is concentrated in defining the internal process to the companies as the prerequisite for successful supply chain management is to coordinate activities within the firm by identifying the key business process and managing them with cross-functional teams (Lambert *et al.* 1998). Although the number of business processes to integrate and manage supply chains might vary, the following seven key business processes have been appointed as critical for SCM: customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, procurement, and product development and commercialization (Cooper *et al.* 1997).

The list below presents the seven business processes in SCM:

a) **Customer relationship management:** involves the identification of key customer target markets and from that implementing improvement initiatives with key customers (Cooper *et al.* 1997). In addition, it includes the establishment of service level agreements with key customers, the proposition of efforts towards demand variability reduction, and implementation of regular performance evaluation initiatives (Lambert and Cooper 2000).
b) **Customer service management:** promotes the direct interaction with the customer supported by information systems (i.e. online order information, production and distribution status) (Cooper *et al.* 1997). In addition, the customer service management must be able to assist the customer with product applications (Lambert and Cooper 2000).
c) **Demand management:** recognizes that the flow of materials and products is connected with the customer's demand and assumes that forecasting and variability reduction are key concerns for the focal company (Cooper *et al.* 1997). Also, the following factors might influence the demand management process: inventory of finished goods, inventory of work in progress, inventory of products

in the pipeline moving from location to location, and customer demand (Lambert and Cooper 2000).

d) **Order fulfilment:** provides the accurate delivery of customer orders (Cooper *et al.* 1997). Lambert and Cooper (2000) stated that performing the order fulfilment process efficiently requires integration of manufacturing, distribution, and transportation planning by implementing alliances with all the key members of the supply chain, including carriers.

e) **Manufacturing flow management:** involves the manufacturing of the most adequate product mix in order to meet customer demand by implementing flexible strategies (Cooper *et al.* 1997). In the SCM context production is pulled through the plant based on customer needs, the orders are processed on a just-in-time basis, and the cycle times are reduced in order to eliminate excessive or un-needed inventories (Lambert and Cooper 2000).

f) **Procurement:** focuses on managing strategic suppliers rather than the traditional bid and buy approach (Cooper *et al.* 1997). Suppliers are also categorised according to their contribution and criticality to the focal company, and in the case of worldwide operations sourcing should be managed on a global basis (Lambert and Cooper 2000). In addition, a set of practices are recommended: long-term strategic alliances with suppliers, early supplier involvement, and information technology integration (Lambert and Cooper 2000).

g) **Product development and commercialization:** manages the introduction of new products in terms of the integration with suppliers in order to reduce time to market (Cooper *et al.* 1997). The reduction of product life cycles requires that new products are launched in shorter timeframes in order to be competitive (Lambert and Cooper 2000). In addition, Lambert and Cooper (2000) indicated that managers in this process must identify the customer's articulated and unarticulated needs, select materials and suppliers in conjunction with procurement, and develop production technology for the product/market combination.

Finally, the product flow and the return process are included in the SCM proposition of business processes (Lambert and Cooper 2000). Cooper *et al.* (1997) emphasized that the focus of the processes should be on meeting the customer's requirements by organizing the firms around them and by eliminating the "silo mentality", moving from a functional approach to a process-based approach.

3.2.2.2.4 Supply Chain Management Components

Lambert *et al.* (1998) reported that a characteristic related to the GSCF framework is the proposition of management components, which might be common across all business processes and members of the supply chain. It has been reported that the level of integration of a business process link is a function of the number and level of the management components added to the link (Lambert and Cooper 2000). In addition, Lambert *et al.* (1998) affirmed that the more management components the better the chance to increase the integration of the business process link. Cooper *et al.* (1997) stated that the management of these components is critical, given that they determine how the business processes are managed and structured.

Based on both supply chain and business process literature, Cooper *et al.* (1997) suggested management components ranging from strategic to operational, physical flow to information flow, tangible structures to organizational structures and cultures. Cooper *et al.* (1997) have stated that each component might have many different sub-components with different relevance levels depending on the process, the organization, and the business link managed. Lambert *et al.* (1998) reported that the key for successful SCM is obtained by understanding each SCM component and sub-component interdependences. The first six components are more tangible and measurable due to their impact on the organization, and the last four are more difficult to assess because they deal with managerial and behavioural aspects (Cooper *et al.* 1997; Lambert *et al.* 1998). The synthesis of the ten components is presented below:

a) **Planning and control:** focuses on how joint planning contributes for SCM success (Cooper *et al.* 1997). Supply chain planning does not change over time in the life of the supply chain (Lambert and Cooper 2000).
b) **Work structure:** indicates how the firm performs its tasks and activities and has been recognized as a critical SCM component (Cooper *et al.* 1997; Lambert and Cooper 2000).

c) **Organizational structure:** refers to implementation of cross-functional integrated teams throughout the supply chain in a process-based environment (Cooper *et al.* 1997; Lambert and Cooper 2000).
d) **Product flow facility structure:** denotes the network structure for sourcing, manufacturing, and delivering across the supply chain aiming at optimizing the entire supply chain, even though some members observe more implications than others (Cooper *et al.* 1997; Lambert and Cooper 2000).
e) **Information flow facility structure:** is indicated to be the first component to be integrated in SCM (Cooper *et al.* 1997; Lambert and Cooper 2000).
f) **Product structure:** coordinates how the product development process should be deployed throughout the supply chain and is directly affected by the level of complexity of the product (Cooper *et al.* 1997).
g) **Management methods:** includes the integration of different corporate philosophies and management techniques (Cooper *et al.* 1997). It is reported that the level of management involvement on a daily basis operation can differ across the supply chain members (Lambert and Cooper 2000).
h) **Power and leadership structure:** influences the form of the supply chain as the most influential player that drives the direction of the chain (Cooper *et al.* 1997). It has been reported that in most supply chains there are one or two strong leaders among the firms (Lambert and Cooper 2000).
i) **Risk and reward structure:** promotes the anticipation of sharing of risks and rewards across the supply chain (Cooper *et al.* 1997; Lambert and Cooper 2000).
j) **Culture and attitude:** deals with the compatibility of corporate culture across supply chain members (Cooper *et al.* 1997). Lambert and Cooper (2000) reported that aspects of corporate culture might include how employees are valued and incorporated into the management of the firm.

The integrated proposition of the GSCF model is presented in Figure 19, which represents the supply chain across the top. Cooper *et al.* (1997) stated that the processes cut the functions within the company and across other companies within the supply chain. From that, it is arguable that each company within the supply chain will have its functional silos related to each key supply chain process (Cooper *et al.* 1997).

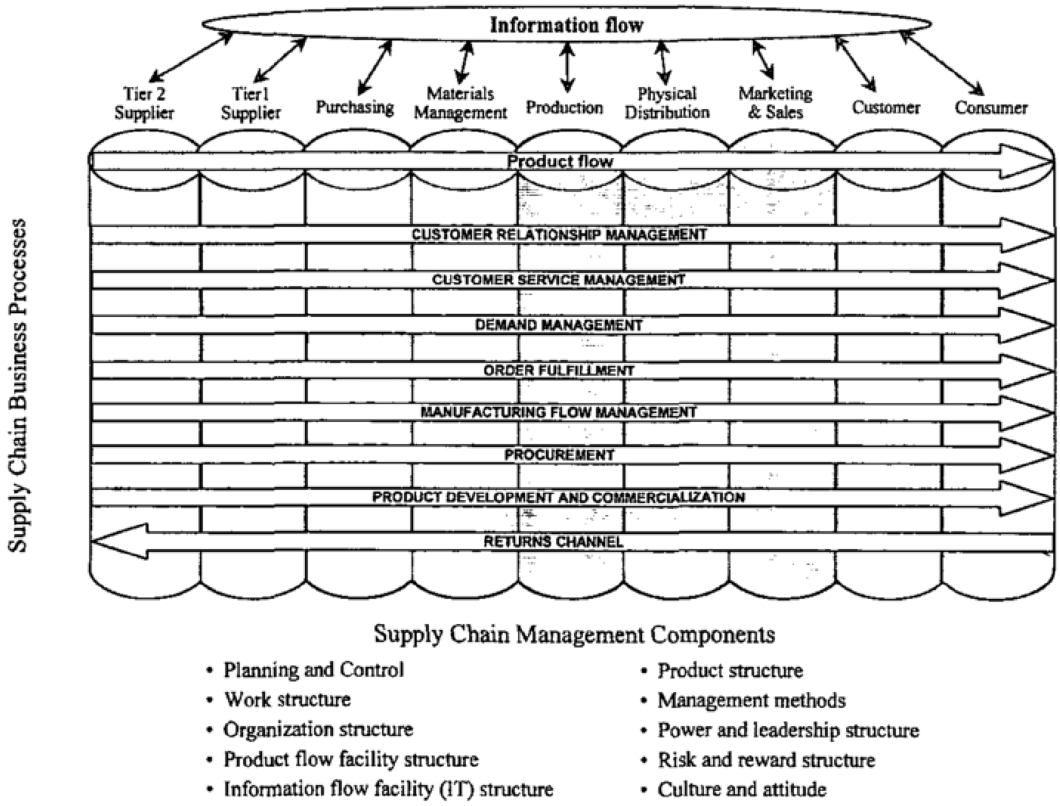


Figure 19 – A framework for supply chain management (Cooper *et al.* 1997)

3.2.3 Best Practices in Supply Chain Management

Over the last 20 years, a number of research developments have been conducted aiming at performance measurement and best practices for managing supply chains. In this section, best practices are reviewed and presented. According to Szulanski (1996), "Practice refers to the organization's routine use of knowledge and often has a tacit component, embedded partly in individual skills and partly in collaborative social arrangements."

3.2.3.1 Performance Measurement and Benchmarking

Measures have been associated with competitive issues in many research developments (Garcia *et al.* 2012; Hult *et al.* 2007; Vachon *et al.* 2009). Competitive priorities constitute the key elements in which a company should focus its efforts for gaining advantage, and therefore structured performance measurement approaches should be implemented in order to do so.

Beamon (1999) indicated performance measurements typically have qualitative and quantitative metrics. In general, quantitative metrics are preferred for SCM performance measurement, given that they are less vague than qualitative measures. Nevertheless, quantitative metrics may not describe precisely a process performance, and they can become inaccurate or difficult to analyse (Beamon 1999). Thus, one can infer that measuring supply chain performance is not an easy task.

At the establishment of the operations management theories, the first competitive priority highlighted was cost. Companies have focused their efforts towards a cost reduction policy via reducing inventory, and optimizing operations and processes, among others. Beamon (1999) defined competitive priorities as dimensions in which a firm's operations are performed, and cost, quality, flexibility, and delivery are the most reported in the literature (Hayes and Wheelwright 1979b). Quality has been nominated as a second competitive priority in conjunction with cost. In this sense, companies have been required to manufacture their products at low costs but presenting high levels of quality. Thirdly, other competitive priorities, such as speed, dependability, and flexibility, have been added to cost and quality.

Melnyk *et al.* (2010) proposed additional dimensions for measuring competitiveness, such as the level of innovation, sustainability, responsiveness, security, and resilience. In this sense, it is reasonable to acknowledge that additional competitive priorities can be added or subtracted according to the company's context. Estampe *et al.* (2013) consider performance measurement in supply chain management a complex task. Such complexity derives from the intrinsic, transversal, and multi-organizational nature of supply chain management, in which several parties are involved.

Childerhouse *et al.* (2003) investigated a set of metrics for construction companies measuring their supply chains. For such a proposition, the following metrics were analysed: delivery lead times, supplier lead times, supplier delivery frequency, and number of suppliers, among others. Generally, it is accepted that these metrics influence project delivery. Construction has a particular character once multiple and concurrent projects constitute the production units (construction sites) of a construction company. In addition, such sites are usually far from each other, including remote locations, which increases the level of complexity for supplying materials.

Garcia *et al.* (2012) proposed a hierarchized approach for measuring supply chain performance as shown in Figure 20. In such a proposition, the different stages of production process are crossed-linked to competitive priorities (also referred to as performance attributes), and afterwards the metrics are deployed into three different levels (Garcia *et al.* 2012). First level refers to global performance, second level to meso, and third level to micro (operational). This proposition presents a highly structured approach for enabling benchmarking not only within a company, but also throughout different parties of the supply chain. In addition, this scheme depicts a detailed description of hierarchies and guidelines for measuring performance, including the definition of which party should receive and analyse each metric. The proposition also addresses properly the roadmap for performance measurement, starting with the process mapping, definition of competitive criteria, description of metrics, and proposition of different managerial levels. In addition to the level differentiation, perspectives from different parties within the supply chain are considered, and therefore the metrics are contextualized for each one of them.

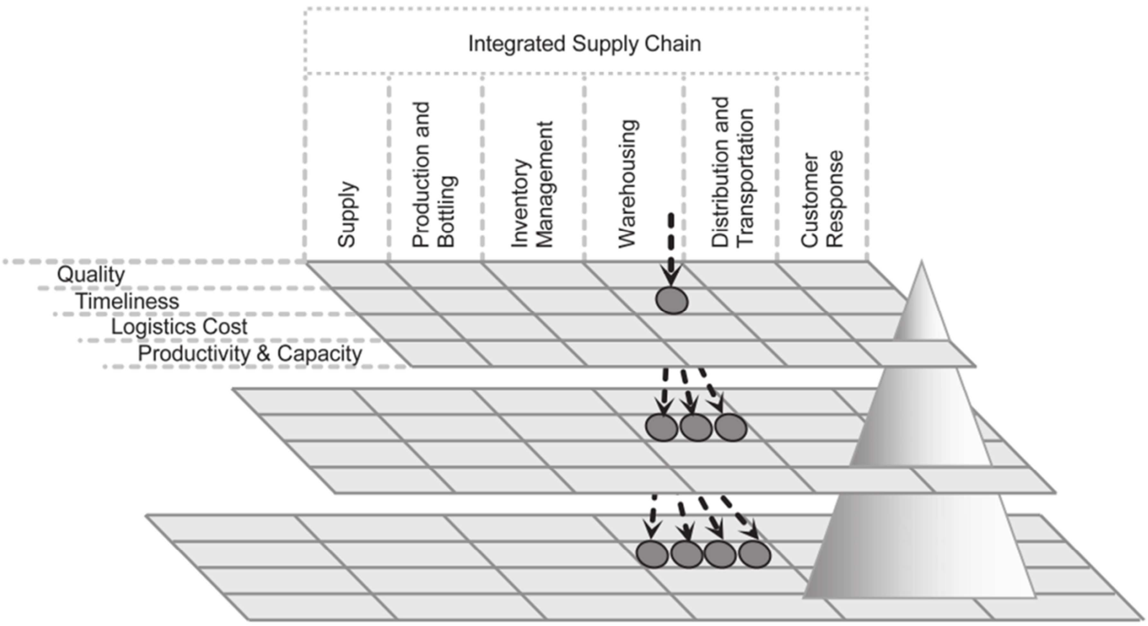


Figure 20 – Hierarchy of performance measures (Garcia *et al.* 2012)

3.2.3.2 Supplier Relationship Management

Ellram and Cooper (1990) reported significant benefits of partnership relationships to supply chain management. These authors categorized such benefits as economic (i.e. cost reduction), managerial (i.e. managing reduced outsourced relationships), and strategic (i.e. positioning the supply chain for competitive advantage). Ellram and Cooper (1990) analysed the benefits from different standpoints (i.e. buyer, seller). These authors concluded that a key challenge for companies is to be sure about which suppliers should be involved in such long-term relationships.

When comparing supply chain management and *Keiretsu*, Ellram and Cooper (1993) found a set of similarities regarding relationship management. "*Keiretsu* is a term used to describe Japanese business consortia which rely on cooperation, coordination, and joint ownership and control to competitively position businesses and industries. While keiretsu are an organizational form, they also represent a methodology, a unique 'Japanese way' of competing, which reflects Japan's culture, economic philosophy and industrial organization" (Ellram and Cooper 1993, p. 2). These authors recommend the adoption of a long-term time horizon, increased information sharing, and joint planning, among others.

Janda *et al.* (2002) investigated long-term manufacturer-supplier relationships. First, these authors maintain that cost reductions are obtained by building and maintaining relationships with key suppliers. Indirect costs of acquisition (i.e. negotiation, paperwork, late deliveries, maintenance of storage areas) are perceived as relevant by purchasing managers (Janda *et al.* 2002). According to these authors, by treating suppliers as allies and sharing information with them they tend to achieve better performance and be more flexible, which contributes to the reduction of indirect costs. Second, Janda *et al.* (2002) found evidence of superior quality in items purchased with suppliers in a long-term partnership. These authors found a connection between improved quality and the implementation of early supplier involvement and supplier development. Such development initiatives of the supply chain were reported as programs to help suppliers organize production, research and development, and scheduling (Janda *et al.* 2002).

3.2.3.3 Supply Chain Risk Management

Supply risks are defined as the occurrence of events that disrupt the inbound supply (Zsidisin and Smith 2005). There are different types of risks. Such risks have diverse root causes and produce a wide range of impacts. Simchi-Levi *et al.* (2014) looked into the impacts of unpredictable events (i.e. super storms, factory fires) in terms of disruption in the automobile industry. Such impacts are mostly concentrated in assessing the time to recovery, which is the amount of time required for a particular supply chain node (i.e. production facility, warehouse) to be fully functional after a disruption (Simchi-Levi *et al.* 2014). By developing a case study in the aerospace sector, Zsidisin and Smith (2005) identified a number of different risk sources: excessive costs, legal liabilities, quality problems, supplier capacity constraints, extended product development times, inability to handle product design changes, and supplier organizational leadership issues. Grimsey and Lewis (2002) evaluated the risks of public private partnerships in infrastructure projects. It was reported by these authors that there are intrinsic sources of risk in the types of project above, including documentation, financing, taxation, and technical details, among others. These examples in three contrasting sectors demonstrate how risk patterns vary significantly.

It was positioned by New (2010) that risks of any type are typically assessed only at the first tier of supply. According to this author, real risks exist upstream in the many tiers of the supply chain. In addition, according to the Construction 2025 report, parties in the UK construction industry still focus on their own individual businesses, rather than share risks and work collaboratively. It has been also reported that tier-1 contractors tend to pass down risks to other supply chain tiers, which will ultimately lead to future legal debates (HM Government 2013).

By identifying and categorizing different sources of uncertainty in construction supply chains, (Gosling *et al.* 2013b) presented a matrix for positioning uncertainties. In the study, these authors categorized uncertainties against their possible sources (i.e. process, control, supply, demand, and external uncertainty). In addition, the impact (in terms of cost and time) and the likelihood of uncertainties were plotted in a scale ranging from 0 to 4. Findings indicate that uncertainties related to control have the highest impact factor (Gosling *et al.* 2013b).

Azambuja and O'Brien (2009) point to reduced flexibility and increased variability as root causes of operational risks in construction supply chains. Typical remedies for reducing such risks are the allocation of inventory, capacity, and time buffers (Azambuja and O'Brien 2009). Risks regarding obsolescence of materials were pointed out as another type of risk in particular supply chains by Holweg and Pil (2001).

3.2.3.4 Flexibility Management

Investigations regarding performance measurement in supply chains have evolved also in accordance with the proposition of the triple-A supply chain by Lee (2004). Agility, adaptability, and alignment comprise the critical aspects for the success of supply chain members (Whitten *et al.* 2012). Agility has been related to responsiveness and time to market (Lee 2004; Whitten *et al.* 2012), and its integration with supply chain management has been referred to in Mason-Jones *et al.* (2000) and Naim and Gosling (2011). It includes the capability of suppliers to work together, and react to variations in customer demand (Whitten *et al.* 2012). Lee (2004) defined adaptability as the aptitude to "adjust the supply chain's design to meet structural shifts in markets; modify supply network to strategies, products, and technologies". Lee (2004) stated that a supply chain's adaptability is tough, but it is a critical issue for delivering sustainable advantage. Whitten *et al.* (2012), in addition, attributed increased relevance to adaptability given the globalization of supply chains. Alignment has been referred to as the capability to promote motivations for supply chain better performance (Lee 2004). Whitten *et al.* (2012) listed in Table 6 a set of practices that companies usually have for fostering agility, adaptability, and alignment.

Table 6 – Triple-A supply chains - adapted from (Whitten *et al.* 2012)

Agility	Adaptability	Alignment
Synchronize the flow of real-time information among supply chain partners.	Monitor world economies to identify new supply bases and markets.	Exchange information freely with suppliers and customers.
Develop strong, long-term, collaborative relationships with suppliers.	Use intermediaries to develop fresh suppliers and logistics infrastructure.	Define clear roles and responsibilities for suppliers and customers.
Design production processes to facilitate postponement.	Evaluate the needs of the ultimate customers as well as immediate customers.	Share risks, costs, and gains of improvement equitably.
Build inventory buffers of inexpensive key components.	Create flexible product designs.	
Develop dependable logistics system or partner.	Determine where products stand in terms of technology and product life cycles.	
Drawing up contingency plans and developing crisis management teams		

Gosling *et al.* (2013a) devised a framework for increasing flexibility in ETO supply chain structures, in which late client changes and diverse forms of variability were identified as problems. The proposition of the framework comprises four basic steps, namely (i) Classify Supply Chain, (ii) Identify and Analyse Uncertainties, (iii) Optimize Pipelines, and (iv) Develop Strategic Flexibility (Gosling *et al.* 2013a). Figure 21 illustrate the supply chain flexibility framework for ETO systems proposed by Gosling *et al.* (2013a).

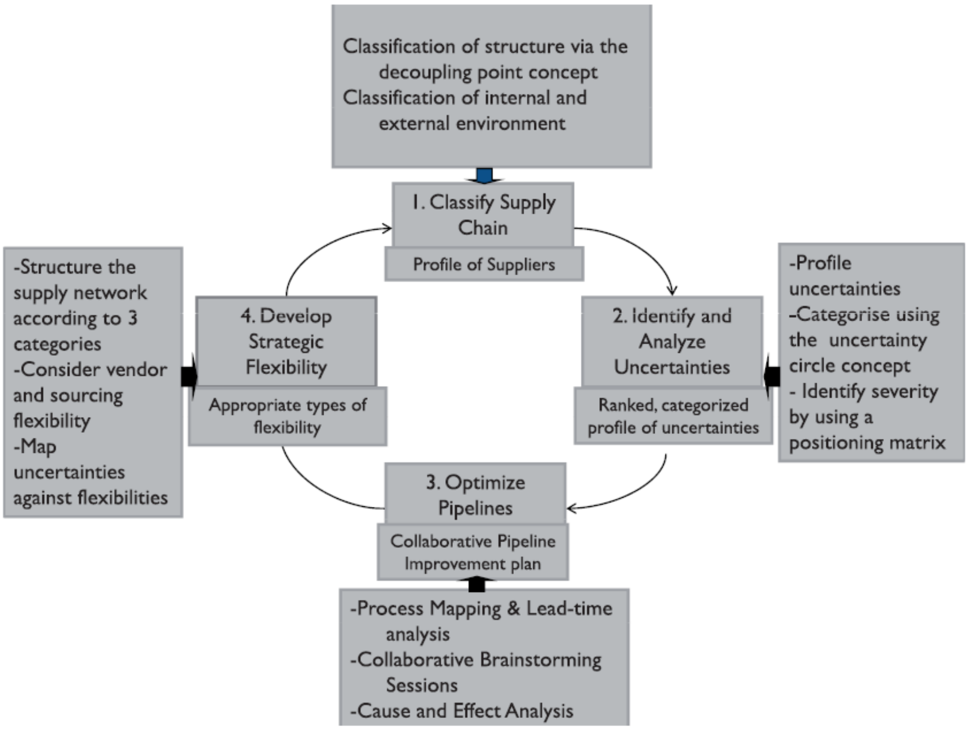


Figure 21 – A flexibility framework for ETO systems (Gosling *et al.* 2013a)

The four basic steps in the framework are listed as follows (Gosling *et al.* 2013a):

- The first step comprises the analysis of strategic stock in the supply chain and the level of customization of products;
- The second step includes five activities: identify the uncertainties, create uncertainty profiles for each project, categorise uncertainties according to supply chain uncertainty source and originator, model interactions between the uncertainties and plot them according to likelihood and impact;
- The third step contains the documentation of techniques (i.e. such as the input–output diagrams, flow charting) applied in conjunction with all supply chain parties in a collaborative environment;

- The final step comprehends the organization of suppliers according to predefined categories and the allocation of mapped uncertainties against flexibilities.

3.2.3.5 Improvement Planning

In order to understand what strategies can contribute to leverage improvement efforts in supply chains, McGinnis and Vallopra (2001) carried out a survey with senior purchasing managers in the manufacturing sector. Findings indicate three key factors for increasing supplier involvement in improvement: high organizational commitment, intense purchasing involvement, and reduced formality in decisions regarding supplier involvement (McGinnis and Vallopra 2001). These authors recognize that such key factors may vary among firms, but in the cases where they are absent it is likely that supply chain improvement efforts would fail.

Drysdale (2013) reported significant improvement initiatives in the UK Highways Agency. Such initiatives are related with 'value for money' generation, and the majority of them are supported by the lean production philosophy. In order to bring the supply chain on board, the UK Highways Agency implemented an assessment tool called the Highways Agency Lean Maturity Assessment Toolkit (HALMAT) (Drysdale 2013). The toolkit was devised to provide guidelines and to assess to what extent suppliers have implemented lean approaches in their businesses. Examples of lean projects implemented with supply partners include streamlined asphalt production, improved preventive maintenance plans to reduce production disruptions, enhanced production scheduling, and just in time delivery of materials on site (Drysdale 2013).

Luu *et al.* (2008) studied how benchmarking, as a means for improvement planning, is able to evaluate and improve construction projects. The study investigated a set of nine KPIs, and a number of sub indicators under each of the original set of KPIs. By comparing internal projects with schemes in different competitors, the company was able to cross-analyse results and capture practices to achieve improved performance (Luu *et al.* 2008).

Foggin *et al.* (2004) proposed a diagnostic tool for determining problems, inefficiencies, or required improvements in supply chains. The proposition is used by third-party logistics (3PL) providers to indicate solutions to be applied in their customers' supply chains. The tool included a set of fourteen hierarchical issues to be identified in supply chains such as those regarding interfaces, pipeline visibility, strategic business units, real time data, among others (Foggin *et al.* 2004). As the tool presented itself as very comprehensive, it can be used as support for devising improvement plans.

Corbett *et al.* (1999) investigated potential benefits regarding joint supply chain improvement in the automobile industry. Reported benefits include improved relationships, reduction of safety stocks and scheduling complexity, diminished rushed orders, implementation of consignment stocks, and more reliable deliveries, among others (Corbett *et al.* 1999). These authors proposed a road map for joint supply chain improvement, divided into six steps:

- **Preparation** includes the selection of parties involved, definition of a timetable, data collection, agreement regarding benefit-sharing;
- **'As-is'** mapping comprises a supply chain map containing physical and information flows;
- **Analysis** encompasses an evaluation of value-added activities, definition of opportunities, and a proposition of redesign;
- **'To-be'** comprises supply chain redesign, definition and agreement regarding an implementation plan, and delineation of performance measures;
- **Management review** indicates an overall presentation and review to all parties involved;
- **Implementation** includes the implementation of the plan, evaluation of performance, and application of eventual adjustments.

3.2.3.6 Information Management

The way information is managed across the supply chain has evolved significantly. A well-known development is the CPFR (collaborative planning, forecasting, and replenishment) methodology (Fliedner 2003). This author defined CPFR as a web-based tool to coordinate activities (i.e. production planning, purchasing, demand forecasting and inventory replenishment) between supply chain partners. Barriers for implementing CPFR include lack of trust in sharing information, lack of forecast collaboration, availability and cost of technology, fragmented information, and difficulties in aggregating information (i.e. number of forecasts and frequency of generation) (Fliedner 2003).

Cassivi (2006) analysed how e-collaboration affects supply chain management in the manufacturing sector. The focus of the study was on collaborative planning and its levels of implementation across the main manufacturer and tier-1 and tier-2 suppliers (Cassivi 2006). Benefits reported by participants include faster and error free transactions, reduced inventory errors, and fewer interactions with customers (Cassivi 2006).

Dawood (2009) reported functional and geographical fragmentations, temporary organizational forms, and the enormous amounts of data (i.e. drawings, photos, cost analysis sheets, budget reports, risk analysis charts) as key barriers for effective information management in construction. In order to tackle such problems, Eastman *et al.* (2011) highlight the role that BIM (Building Information Modelling) plays in information management in the construction industry. BIM capabilities regarding information management include continuous tracking of costs, integration of specifications, and design performance analysis (i.e. energy, air flow, lighting) (Eastman *et al.* 2011). BIM promotes a collaborative environment for integrating supply chain parties, given that models share relevant information in real time.

3.2.4 Characteristics of Construction Supply Chains

By devising a generic framework such as SCOR, which was one of the first propositions for managing supply chains in the manufacturing sector, Cooper *et al.* (1997) proposed a set of questions for future research. One of these questions is placed as a guideline for discussion: *are supply chain processes the same for all companies?*

Fisher (1997) stated supply chain approaches must match product characteristics. Gosling *et al.* (2012) argue that there is no more room for a 'one-size-fits-all' approach for supply chain management: companies have different types of supply chains based on their diverse uncertainty patterns. Gosling *et al.* (2012) discuss that the development of managerial processes must be tailored to attend such patterns.

Supply chain structures generally reflect characteristics of production strategies, which were described early in section 3.1.1.2. Supply chain structures are concerned about the flow and control points along with the supply chain, and they are presented as buy-to-order, make-to-order, assemble-to-order, made-to-stock, and ship-to-stock (Gosling 2011). However, the existing structures do not totally match the characteristics of project-based production systems. Hicks *et al.* (2000) maintain that there is limited research in supply chain management in the ETO sector when contrasted with high-volume production sectors such as electronics and automotive.

Gosling (2011) discusses an emerging supply chain structure, called the ETO supply chain. ETO supply chain structures can be found in supply chains where the OPP is located at the design stage, which typically occurs in sectors related to complex project environments such as those in construction and capital goods (Gosling and Naim 2009). O'Brien *et al.* (2009) outline the task of managing construction supply chains as the coordination of discrete quantities of materials and specialty services to be delivered to specific projects' sites. Such an approach points to the idea of numerous and individual supply chains sourcing particular projects, which is the standpoint frequently adopted by construction companies. Although the construction industry has valued the importance of supply chain management in its business scenario, research in this area can still be considered as immature (Gosling *et al.* 2013b).

In order to characterize CSCM, six key features of construction supply chains are discussed. Such features comprise project-based nature, network design, interfaces, supplier base, fragmentation, and demand forecast.

3.2.4.1 Project-based Chains

According to Elfving *et al.* (2005), project-based production systems tend to have projects with a long duration, mostly because of their long product delivery lead times. In addition, such systems are naturally influenced by external factors such as the logistics of materials and crews, and procurement routes. Luhtala *et al.* (1994) emphasize how the flow of materials is considered in project-based production systems, which impacts on the adoption of converging logistics directed to the construction sites. Luhtala *et al.* (1994) suggest that converging logistics require the anticipated confirmation of the customers' orders, in which instructions for customization are registered early for production at the design stage. Vrijhoef and Koskela (2000) support the concept of converging logistics, in which the flow of materials and services is directed to the construction site, where the 'construction factory' is arranged in a fixed position layout. Supply chains presenting converging logistics are characterized by low volume, highly customized products, and they follow a pull control system. Usually, their performance measures are in terms of quality, punctuality, and delivery time (Luhtala *et al.* 1994). Figure 22 illustrates how converging logistics is organized in supply chains.

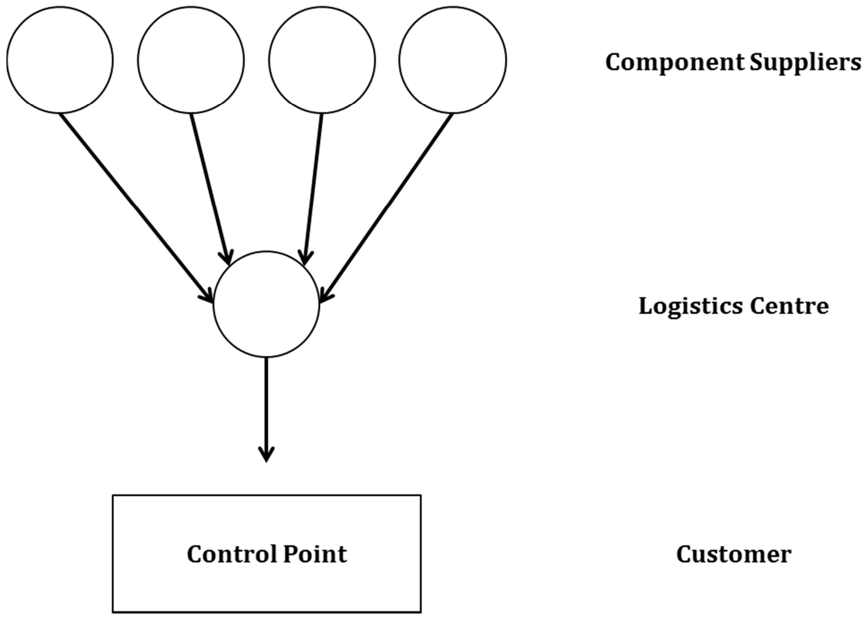


Figure 22 – Converging logistics - adapted from (Luhtala *et al.* 1994)

Gosling *et al.* (2013b) and Vrijhoef and Koskela (2000) argue that ETO supply chain structures are typically constituted by temporary organizational forms and site-based operations. Morledge *et al.* (2009) contends that supply chains in construction are treated as temporary, given that different parties are focused on completing their small, and often unique, parts in a project. Purvis *et al.* (2014) suggest that increased supply chain flexibility should be pursued by construction companies, especially because it helps to deal with temporary networks of suppliers. It is emphasized that flexible networks can be reorganized rapidly, and by doing so 'low cost penalties' are produced (Purvis *et al.* 2014). The aforementioned focus extend the temporary nature of projects towards the supply chain: construction supply chains have also been managed on a temporary basis. Formoso and Isatto (2009) emphasize the nature of construction supply chains as temporary multi-organizations, which are initiated, developed, and disbanded during a project.

3.2.4.2 Specific Network Design

The typical design of a construction supply chain is complex and affects day-to-day activities and processes (Bankvall *et al.* 2010). Dainty *et al.* (2001) characterized the design of construction supply chains as having the main contractor at the centre of the network, in which the construction company has different links with suppliers, clients, and designers, among other parties involved. It is worth mentioning that, from the perspective of a contractor, there are multiple and concurrent projects co-existing all the time (Souza and Koskela 2014). Figure 23 illustrates a construction supply chain from a project's perspective.

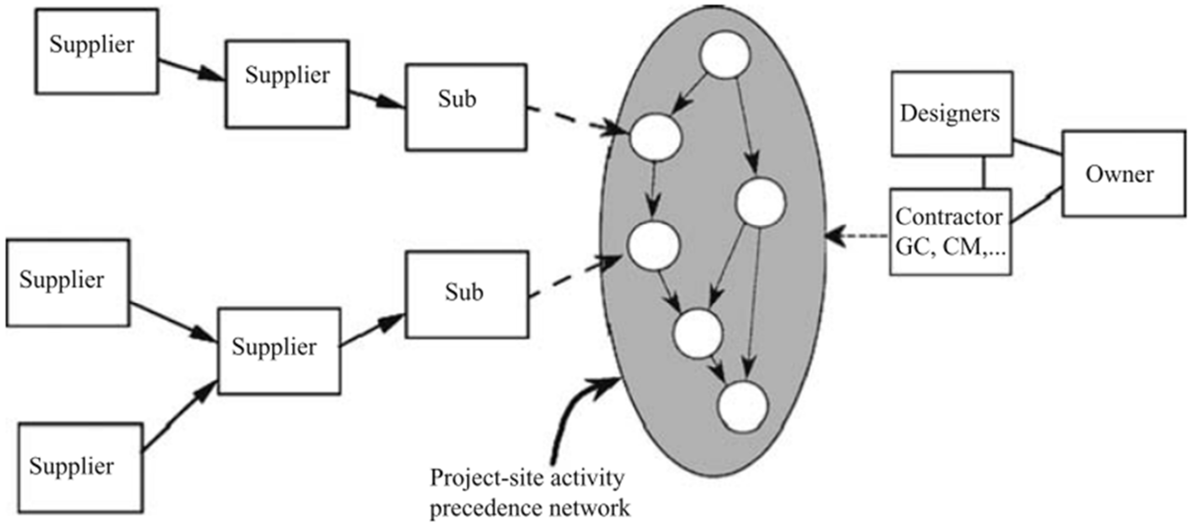


Figure 23 – Project supply chain (Azambuja and O'Brien 2009)

The complexity in moving crews and materials from suppliers to projects' sites is significantly amplified as the number of parties in the network is increased. In addition, Azambuja and O'Brien (2009) noted transient locations as a key characteristic in the structure of construction supply chains. The combination of multiple, concurrent, and widely spread projects contributes to the augmented complexity in the task of managing construction supply chains, as noted by Souza and Koskela (2014).

When analysing the interfaces between site activities and the supply chain, Vrijhoef and Koskela (2000) highlighted the existing impact of supply chain variability on works on site. Azambuja and O'Brien (2009) discussed the problem of variability in CSCM, and mapped three possible sources for the problem: supplier performance, the manufacturing process itself, and customer demand. On the side of suppliers' performance, Vrijhoef and Koskela (2000) considered the adoption of buffering initiatives. In order to respond to variability, managers might incorporate buffers throughout the different tiers of the supply chain. In addition, Naim *et al.* (1999) and Naylor *et al.* (1999) refer to push-pull systems upstream and downstream the OPP in order to increase responsiveness.

The improvement of the total supply chain is recommended to increase dependability of deliveries (Vrijhoef and Koskela 2000). By improving supply chain dependability, direct and indirect implications (i.e. disruption of works, cost overruns) of poor delivery performance can be reduced, or ultimately eliminated. Last minute schedule changes requested by the customer are also listed as a root cause of common problems found in low volume supply chains (Luhtala *et al.* 1994; Gunasekaran and Ngai 2005).

3.2.4.3 Interfaces

Construction supply chains comprising multiple organizations and embracing a set of activities have an increased level of complexity. Such activities occur in three streams, namely information flow, materials flow, and capital flow (Luhtala *et al.* 1994). For connecting such flows, there are different interfaces, which are the links between contractors, suppliers, and concurrent projects. Vrijhoef and Koskela (2000) argued that managing supply chain interfaces produces significant improvement in project delivery due to enhanced information, materials, and capital flows. Problems located at interfaces interfere in the continuous flow, and consequently they generate waste (Souza and Koskela 2014).

Azambuja and O'Brien (2009) characterized construction supply chains' flows as slow, created and recreated several times during the project, and lacking in Information Technology (IT) tools for their support. Equally important, previous research has found the problems of construction supply chains mostly located at the interfaces between different parties of the supply chain (Luhtala *et al.* 1994; Vrijhoef and Koskela 2000). It is clear that the level of reliability regarding resource allocation is reduced at the interfaces between subcontractors (Sacks 2009). Figure 24 shows examples of interfaces and problems related to them in low volume supply chains.

The understanding of supply chain interfaces in the construction sector can be linked to the OPP concept. Barlow *et al.* (2003) apply these views to understand how the decoupling point of standardized components is positioned at the factory-supplier interface, which contributes to increased responsiveness according to his findings. These authors studied data from the house building industry in Japan.

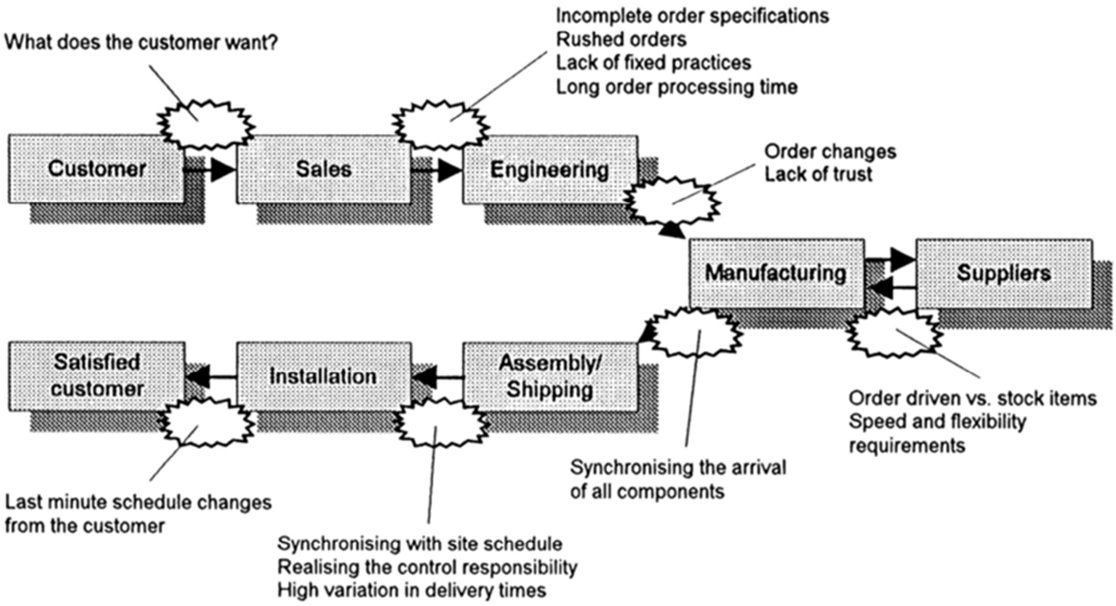


Figure 24 – Problems in make-to-order supply chains (Luhtala *et al.* 1994)

3.2.4.4 Supplier Base

According to Cox and Ireland (2002), there are a number of possibilities regarding the types of suppliers' relationships in the construction sector, including those purely independent transactional and price-based interactions. Koskela and Vrijhoef (2001) underlined the 'myopic' control and unstable organization of construction supply chains as barriers for problem solving and innovation.

In construction supply chains, numerous transactional, price-based, and unstable relationships lacking in trust can be found, which directly affect the characteristics of a supplier base. The ways supplier bases are organized include:

- The effective selection of suppliers, including the way services or materials are consolidated (Cox and Ireland 2002). Ireland (2004) points to the existence of low entry barriers in construction supply chains. It is argued by Sacks (2009) that the assignment of works to fewer subcontractors should be fostered;
- Gosling *et al.* (2010) report findings from a case study in which the total supply chain network is organized in different categories of suppliers: approved, preferred, and framework agreement. Such categories, according to these authors, are used as a means to standardize sourcing decisions both at project and business levels;

- Cousins (1999) studied supplier base reduction and its effects in different industrial sectors, including 'project/construction'. This author emphasized that firms commonly adopt different supplier base approaches (i.e. supply base reduction) without taking into consideration factors such as market dynamics and a clear assessment of the cost and benefits involved, among others.

It also should be highlighted that in construction supply chains there are suppliers with different production strategies. Azambuja and O'Brien (2009) presented a discussion regarding the Product-Process Matrix illustrated in Figure 9. Such discussion emphasized two important aspects. First, a typical supply chain includes companies presenting different production characteristics, which can range from job processes to continuous flow processes (Azambuja and O'Brien 2009). Second, Azambuja and O'Brien (2009) indicate the application of the Product-Process Matrix for evaluating supply chain capabilities.

3.2.4.5 Fragmentation

Construction supply chains tend to be fragmented environments (Gosling and Naim 2009; Dainty *et al.* 2001). Later, Gosling *et al.* (2014) continue to highlight the 'persistent weakness' regarding structural fragmentation in construction. These authors review the literature and point to the 'slow' speed in which construction implemented supply chains management practices. Bankvall *et al.* (2010) maintain that the management focus has been limited to the project environment, given the lack of uniformity in the pipeline of projects in construction (Gosling *et al.* 2014). Gosling *et al.* (2014) emphasized that previous research has questioned the achievement of full supply chain integration. In addition, the same authors indicate the need for a contextualized framework focused on reducing fragmentation in ETO supply chain structures.

Tommelein *et al.* (2003) stated that due to their finite duration, construction projects are less responsive to improvement efforts. These authors discussed the project-by-project mind-set found in the construction industry, which contributes to the generation of high levels of two-party contracts. Such contracts typically lead to adversarial and price-driven decisions (Tommelein *et al.* 2003).

Cox and Ireland (2002) suggested that fragmentation in construction is inherent due to the incompatible nature of demand and supply in the sector. These authors report a historical number of complex structures of power regarding suppliers of materials and subcontractors. The wide range of products and services (i.e. commodity components, highly specialized services) is listed as a source of fragmentation (Cox and Ireland 2002).

Dainty *et al.* (2001) defend that construction companies are able to streamline their supply chains by implementing long-term relationships with suppliers, such as those observed in the manufacturing sector. Such a proposition is based on the fact contractors tend to repeat suppliers on a frequent basis. Findings indicate a limited appetite for integrating the different parties in construction supply chains. Dainty *et al.* (2001) reported negative attitudes among supply chain organizations regarding essential requirements for aligning processes, systems, and procedures in order to achieve improved performance.

3.2.4.6 Demand Forecast

Ireland (2004) points out that demand is a key variable in supply chain management. First, this author discusses that often clients do not know their own demand patterns, so that they face opportunistic behaviour in contractors in the market. Ireland (2004) characterizes construction companies as 'integrators' of multiple supply chains. Such supply chains contain volatile, unpredictable, and customer-driven demand patterns (Ireland 2004).

There is limited demand forecast in ETO supply chain structures when compared to those in the make-to-stock sectors (Gosling *et al.* 2013b). These authors highlight that ETO supply chains have increased uncertainty produced by high levels of customization, project specific designs, among others.

Difficulties in demand forecasting derive from the early OPP found in construction supply chains, in which works start only after an order is placed (Olhager 2003). The OPP related to the ETO production strategy is pointed at design, the earliest stage of production activities, according to Figure 10. According to this proposition, companies adopting the ETO production strategy deal with real demand, given that they do not plan their production schedule based on demand forecasts. Infrastructure, industrial, and commercial projects have decreasing levels of repeatability given that they are highly customized. Gosling *et al.* (2014) argue that traditional forecasting systems using demand smoothing could not be applied in construction, given to the complexity of projects' demand patterns.

In order to comply with reduced information regarding demand forecast, Gosling *et al.* (2014) support the utilization of tactics derived from FORRIDGE principles. Particularly for the case of demand uncertainty, Gosling *et al.* (2014) recommend the adoption of a tactic named as 'Sharing Demand Information', which is categorized under the principle of 'Information Transparency'. Gosling *et al.* (2014) suggest that accurate and non-biased information regarding demand (i.e. inventories, specifications, work in progress, flow rates) should be available to all relevant parties involved in a project in order to avoid misrepresentations.

3.2.5 Summary and Critique

The concept of Supply Chain Management was then presented. Different viewpoints and developments were taken into account, leading to a consensual view that SCM evolved from a logistics approach to a multi-organizational complex process. The evolution of such views ranged from Ellram and Cooper (1990) though Cooper *et al.* (1997), Simchi-Levi *et al.* (2000), and Schniederjans *et al.* (2010) to Gosling *et al.* (2012). In addition, these developments were analysed in terms of their fit into the production template described by Koskela (2000).

The review focused on the two best known and most accepted process-based frameworks, namely SCOR and GSCF. These well known frameworks for managing supply chains have been researched within the manufacturing sector, especially in companies adopting the Make-to-Stock (MTS) production strategy. Supply chain management in the MTS environment has particular premises, and the most relevant one is demand predictability. MTS supply chains are driven by demand, and therefore they can balance and schedule production based on demand patterns. Both SCOR and GSCF schemes are treated in the literature as process-based or process-oriented. Both propositions suggest a set of procedures, activities, methods, tools, techniques, and metrics to be adopted by companies. Justification for adopting the aforementioned approaches is referred from previous business developments. SCOR and GSCF are frameworks composed of internal elements, and these elements are structured into different parts, namely a system supported by metrics and managerial practices to be implemented by companies. It is not clear in the literature whether these SCM frameworks are supported by a production theory or if they are based on social aspects aiming at improving relationships between companies. SCOR and GSCF seem to focus on supply chain flow, especially regarding material and information. Nevertheless, both frameworks do not address supply chain elements within the flow, such as waiting and other inefficiencies. In addition, SCOR and GSCF do not discuss how to manage supply chains in a project-based company, such as those using the Engineer-to-Order (ETO) production strategy. ETO companies have their production system driven by orders, which require decisions to be made by the customer from the early design stages.

A set of practices was reviewed in order to provide the basis for the development of the framework proposed. From a SCM perspective, construction companies should not only develop and implement best practices, but also disseminate them in their supply chains. Initially, six practices were studied from the literature: performance measurement and benchmarking, supplier relationship management, supply chain risk management, flexibility management, improvement planning, and information management. As proposed in the research method, this initial set of practices will be combined with additional practices to be found in the case studies.

The key characteristics of construction supply chains were summarized in six streams: project-based chains, network design, interfaces, supplier base, fragmentation, and demand forecast. Companies adopting the Engineer-to-Order production strategy face a number of challenges for managing production and ultimately supply chains. Such challenges comprise, among others, the variety of suppliers, the lack of demand predictability, and the uniqueness of projects. General characteristics of construction supply chains reviewed in the literature are summarized in Table 7.

Table 7 – Characteristics of construction supply chains

Characteristics of Construction Supply Chains	Salient Points	Key References
Project-based Chains	Early definition of specifications Converging logistics flows Suppliers participate in small and unique parts Need for revised strategies supporting flexibility Temporary supply chains	Luhtala *et al.* (1994), Vrijhoef and Koskela (2000), Elfving *et al.* (2005), Formoso and Isatto (2009), Gosling *et al.* (2013b), Purvis *et al.* (2014)
Specific network design	Increased complexity due to multiple, concurrent, and widely spread projects' sites Suppliers' performance presents variability due to design Intrinsic need for flexible strategies in order to increase competitive advantage	Luhtala *et al.* (1994), Gunasekaran and Ngai (2005), Naim *et al.* (1999), Naylor *et al.* (1999), Vrijhoef and Koskela (2000), Azambuja and O'Brien (2009), Bankvall *et al.* (2010), Dainty *et al.* (2001), Gosling *et al.* (2013a), Souza and Koskela (2014)
Interfaces	Multiple interfaces Three essential flows: materials, information, and capital Problems are located at the interfaces	Luhtala *et al.* (1994), Vrijhoef and Koskela (2000), Barlow *et al.* (2003), Azambuja and O'Brien (2009), Souza and Koskela (2014)
Supplier base	Large and highly specialized Diverse (i.e. different production strategies) Poor and unstable control Transactional relationships and low entry barriers Guidelines are generally 'misunderstood' (i.e. supplier selection, supplier base reduction)	Cousins (1999), Koskela and Vrijhoef (2001), Cox and Ireland (2002), Ireland (2004), Azambuja and O'Brien (2009), Bankvall *et al.* (2010), Gosling *et al.* (2010)

Table 7 – Characteristics of construction supply chains (continuation)

Characteristics of Construction Supply Chains	Salient Points	Key References
Fragmentation	Fragmentation is inherent to the business Structural and widely spread Sources of fragmentation are well known Types of fragmentation are not categorized Project-by-project mind-set and lack of regularity in the pipelines Adversarial and price-driven decisions Short-term relationships	Dainty *et al.* (2001), Gosling and Naim (2009), Bankvall *et al.* (2010), Gosling *et al.* (2014)
Demand Forecast	Key variable in construction supply chains Volatile, unpredictable, and customer-driven Increased uncertainty due to high levels of customization Early OPP Traditional forecasting systems using demand smoothing do not work Need for information sharing (i.e. inventories, specifications, work in progress, flow rates)	Olhager (2003), Ireland (2004), Gosling *et al.* (2013b), Gosling *et al.* (2014)

3.3 Conceptual Views of Production and Supply Chain Management

Concepts regarding TFV, Lean and Agile developments, the Logical Factory, Project Supply Chains vs. Enterprise Supply Chains, and Matching Production and Supply Chain Management are presented in this section.

3.3.1 TFV

Koskela (2000) referred to a production template composed of design, operation and control, and improvement tenets. This template gives significant insights for understanding production systems from a wider perspective:

- **Design** refers to the division of work both horizontally and vertically, including layout positioning (Koskela 2000);
- **Operation and Control** comprises the preparation of plans to be realized by operatives (Koskela 2000);
- **Improvement** concentrates on variability elimination and implementation of performance measures focusing on waste eradication (Koskela 2000).

Based on such a template, Koskela (2000) discussed three central principles, namely Transformation, Flow, and Value (TFV):

- The view of **Transformation** comprises the transformation of inputs to outputs. Managing production equals to the decomposition of the total transformation into basic tasks and minimization of costs;
- The view of **Flow** encompasses the reduction of non-value adding activities. It has been determined that variability is a key variable for achieving improved flows. It recommends the compression of lead times, reduction of lead times, simplification of processes, increased transparency, and augmented flexibility;
- The view of **Value** refers to the improvement of value to customers. It indicates the application of methods, tools, and techniques to capture these needs and convert them into a precise design solution to be manufactured accordingly.

3.3.2 Lean and Agile Concepts in Supply Chain Management

The application of the lean principles has led companies to achieve world-class operations. In the same sense, many companies have incorporated supply chain management practices in order to obtain better results not only by their own efforts but also from developments of their supply chain members.

Schniederjans *et al.* (2010) debate that the combination of lean and supply chain management involves the application of all lean principles within a supply chain management context, representing a nexus of two areas into a new set of guiding principles. The discussion regarding the influence and contributions of lean to the design, operation, and improvement of supply chain management is based on the nexus defined by Schniederjans *et al.* (2010) for lean and supply chain management. The interface between lean and supply chain management is closely related to governance. Governance is about coordinating efforts, which is highly complex in single or multiple companies. Schniederjans *et al.* (2010) argue that an upper-level position, such as a vice-president, is required to support and coordinate the implementation of lean practices within the organization. Such a recommendation is due to the need of a clearly established champion to assure the application of the lean principles.

Naylor *et al.* (1999) state that there are paradigms in operations management, among them lean thinking and agile manufacturing. According to these authors, the combination of these two paradigms is a key issue to design effective supply chains. The market competition forces decision makers not only to choose but also to implement them in order to have competitive advantage.

In the context of construction, projects have been characterized by requiring multidisciplinary design and fabrication skills from their supply chains (Eastman *et al.* 2011). Gann (1996) explored the interrelations between construction and manufacturing production approaches. The findings from the study showed construction companies can adopt methods from manufacturing, but the study has also shown the interrelation as a two-way learning process. ETO-SCM design is a critical stage in the proposition of this study due to the dynamics of its environment, involving highly customized products, low volume of production, and multiple organizations.

Mason-Jones *et al.* (2000) state that new strategies should be developed in order to match appropriately demand and supply, and that such strategies should also be differentiated according to the markets and products produced. When governance shifts from a single company to a set of different companies a different approach is required. Research initiatives such as those developed by Christopher and Towill (2000), Naylor *et al.* (1999), and Mason-Jones *et al.* (2000) attempt to define recommendations for improved supply chain design. Such propositions refer to the application of contextualized SCM approaches upstream and downstream the decoupling point, in order to have increased response to customer demand, as shown in Figure 25. There are different demand patterns upstream and downstream the decoupling, which results in unpredictable stock (Naim and Barlow 2003; Naylor *et al.* 1999). Demand upstream is smoothed and easier to manage when compared to unstable demand patterns downstream the decoupling point.

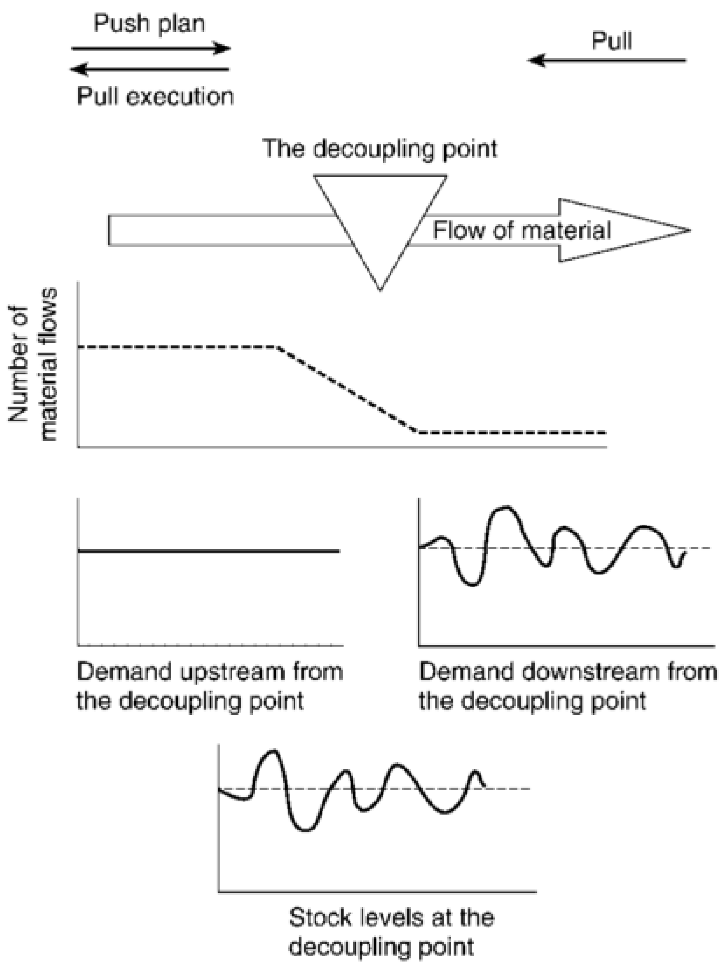


Figure 25 – Implications of the decoupling point in SC (Naim and Barlow 2003)

In order to tackle this problem, standardization of materials is highly recommended for the construction sector (Gann 1996), once standardized materials contribute to reducing complexity within the supply chain. In addition, prefabrication of components and their assembly on site contribute widely to reduced costs, increased speed of construction, and improved quality (Gann 1996). Prefabrication is an enabler for postponing product differentiation, and can produce a more balanced production planning as presented by Rocha and Kemmer (2013). Dividing work packages into activities that should be performed upstream and downstream the OPP improves project delivery not only within the production site, but also throughout the supply chain. Although implications of delayed product differentiation in construction produce positive effects in supply chain management, its incorporation requires intensive planning and early coordination.

3.3.3 Supply Chain as a Logical Factory

It is indicated that production systems management has chronologically evolved from individual work operations through factories to supply chains (Luhtala *et al.* 1994). These authors stated that the same production planning and control methods applied in single factories should be used to manage low volume supply chains, and therefore the latter should be managed as logical factories.

According to Luhtala *et al.* (1994) there are three analogies to be made between factories and supply chains. First, the **structural analogy** is illustrated in Figure 26 and discussed below by Luhtala *et al.* (1994):

- Component factories are as component cells producing components for the final products;
- The logistics centres are as assembly cells, receiving different parts from component factories under a pull production strategy;
- Local front-line units should be managed as customer service areas.

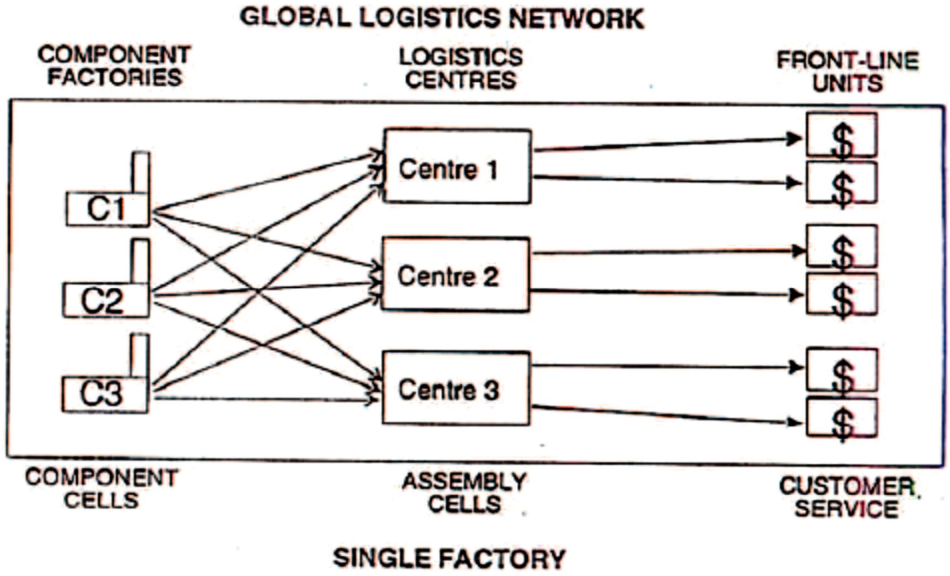


Figure 26 – Structural analogy (Luhtala *et al.* 1994)

Second, there is an **objective analogy**, which is related to the common objective of factories and a supply chain regarding financial success (Luhtala *et al.* 1994). Common competitive aims of factories and supply chains, in order to achieve customer satisfaction and internal efficiency, are listed as follows by Luhtala *et al.* (1994):

- Short delivery time;
- High delivery punctuality;
- High quality;
- High flexibility;
- Low capital investments;
- Low costs.

Third, there is a **control analogy**. Although there are organizational boundaries and geographical aspects to be considered, the instruments for controlling a factory and a supply chain are the same (Luhtala *et al.* 1994). It is maintained that a factory is a comparable unit to a supply chain as a manufacturing cell in the context of a factory (Luhtala *et al.* 1994).

3.3.4 Project Supply Chains vs. Enterprise Supply Chains

The perspective regarding construction supply chains includes multiple suppliers, sub-contractors, contractors, designers, and the owner, among others. All these parties are included within the context of a single project, and construction companies tend to have multiple and concurrent projects.

Managing construction supply chains implicates not only project supply chains, but also enterprise supply chains. The Enterprise supply chain comprises all project supply chains of a particular construction company. Thus, by having 2 management levels (enterprise and project) construction companies have an additional interface to be managed (Ayers 2004). In this context, this internal interface requires integrated efforts both at the project and enterprise levels as enablers for improved project delivery (Souza and Koskela 2013).

Azambuja and O'Brien (2009) stated that project supply chains are unstable due to the lack of reliability of site production systems. In addition, information flow is limited and therefore material orders, and construction schedules, among others, are not regularly available for supply chain parties (Azambuja and O'Brien 2009). Again, such lack of stability spreads throughout different and concurrent projects within the construction company.

Ayers (2004) presented an extensive discussion regarding supply chain management in projects. Such discussion highlights coordination aspects at the project level and its basis lay in the traditional view of Project Management advocated by the PMI (Ayers 2004). In addition, the proposition of Ayers (2004) is to manage project supply chains according to the SCOR model.

Enterprise supply chain management in construction requires a well-developed strategy. By having Business Process Reengineering (BPR) as a background, Childerhouse *et al.* (2003) defined three levels for tackling supply chain problems in the construction sector: strategic, tactics, and operational. These authors proposed guidelines for each one of the levels, and such guidelines are streamlined and extended across supply chain, as shown in Figure 27.

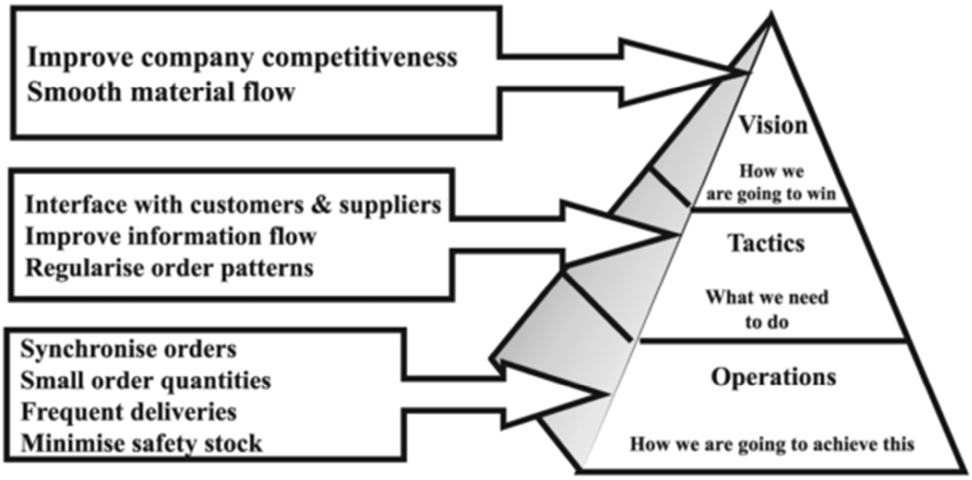


Figure 27 – Supply chain strategy (Childerhouse *et al.* 2003)

3.3.5 Matching Production and Supply Chain Management

Early in the late 1990s, Fisher (1997) presented a discussion regarding products and supply chain approaches. The proposition defined two categories of products, namely functional and innovative. Such categorization was based on product life cycle, contribution margin, predictability of demand, product variety, average margin of error in the demand forecast, stock out rate, and lead time, among others (Fisher 1997). As a theoretical contribution, Fisher (1997) proposed a matrix relating his two different types of products and two different supply chain management strategies. Such a matrix has been proposed as a decision support tool for matching products and supply chain approaches.

Later, products' characterization included the degree of customization, volume of production and diversity of raw materials and components (Olhager 2003), and predictability of demand, product variety, and lead times for production (Qi *et al.* 2009). In the same context, Childerhouse *et al.* (2002) proposed additional variables such as duration of life cycle, time window for delivery, and variability for the product's characterization.

According to Childerhouse *et al.* (2002), matching product characteristics with supply chain management produces a massive decrease in product development time, significant reduction in manufacturing costs, and substantial diminution of delivery lead times. In their proposition, these authors have aligned product life cycle stages with different strategies for managing demand chains, as shown in Figure 28. As the different life cycle stages evolve from introduction to decline, the method proposed by Childerhouse *et al.* (2002) established strategies for managing demand, starting in 'design and build' and finishing in the 'material resources planning' phase.

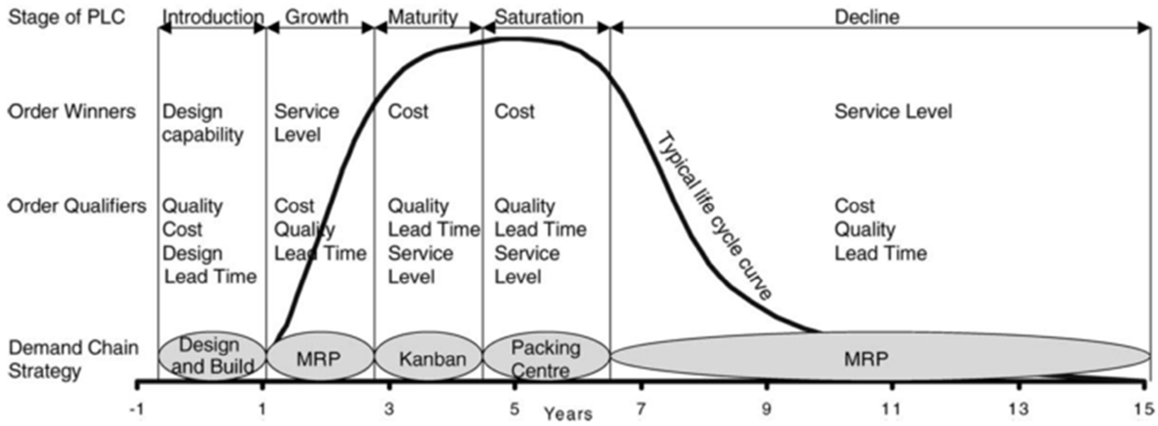


Figure 28 – Generic product life cycles and demand chain strategies (Childerhouse *et al.* 2002)

3.3.6 Summary and Critique

The study of a theory of production, developed by Koskela (2000), has contributed to the definition of a production template comprised of three tenets: design, operation and control, and improvement. In addition, this author proposed three principles for managing production: transformation, flow, and value (TFV). Such principles have significant impact in construction management, an area of research interconnected with the present study.

Construction companies are highly affected by the position of their Order Penetration Point (OPP). Literature regarding the OPP concept focused on its implications in production and mass-customization strategies, but failed to address its benefits for supply chain planning. The *leagile* concept presented by Mason-Jones *et al.* (2000), in which different production approaches are proposed upstream and downstream the decoupling point, makes a positive attempt for using the OPP as a reference for production and supply chain management. This proposition contributed to reducing inventories and increasing continuous flow upstream the decoupling point (lean production), and focused on pre-assembly and modularization downstream the decoupling point. Nevertheless, the emphasis on how supply chain improvement can be supported by the positioning of the OPP has not been made clear. From a critical perspective, by considering the OPP in supply chain improvement the company is able to produce improved flow, a critical topic in ETO supply chain structures.

Three analogies were identified between low volume supply chains and factories. First, there are structural similarities to be considered (i.e. component cells as component factories). Second, there is a mutual objective concerning low volume supply chains and factories: to make money in the long run. In order to achieve such an objective, there are aims at the operational level: short delivery time, high delivery punctuality, high quality, high flexibility, low capital investments, and low costs. Finally, there is a control analogy once the instruments for controlling a factory and a supply chain are the same.

The identification of multiple actors in construction supply chains is discussed. In addition, the existence of multiple and concurrent projects in construction companies is declared. These projects are 'one-of-a-kind' and require customized materials and subcontractors. The need for a comprehensive approach to manage supply chains comprising both the project and the enterprise levels is also emphasized.

Product characteristics are the input for selecting and reviewing production strategies. Different variables (i.e. product features and characteristics) influence production, and ultimately supply chain management. Such effect occurs not only in its operation, but also in its design and improvement. Companies should realize which implications their products have on supplier base, supplier alliances, and performance measurement, among other issues.

4 UNDERSTANDING THE PROBLEM

The task of understanding the problem is detailed in this chapter. The strategy herein adopted is based on exploratory research, so that an initial view regarding the field of study can be achieved based on Exploratory Interviews and Case Study 1 (Part 1), as shown in Figure 29. The interviews were carried out with academics and practitioners in Brazil and in the UK. The case study, developed in Company A from Brazil, aimed at obtaining a wider view of the characteristics of construction supply chains in practice.

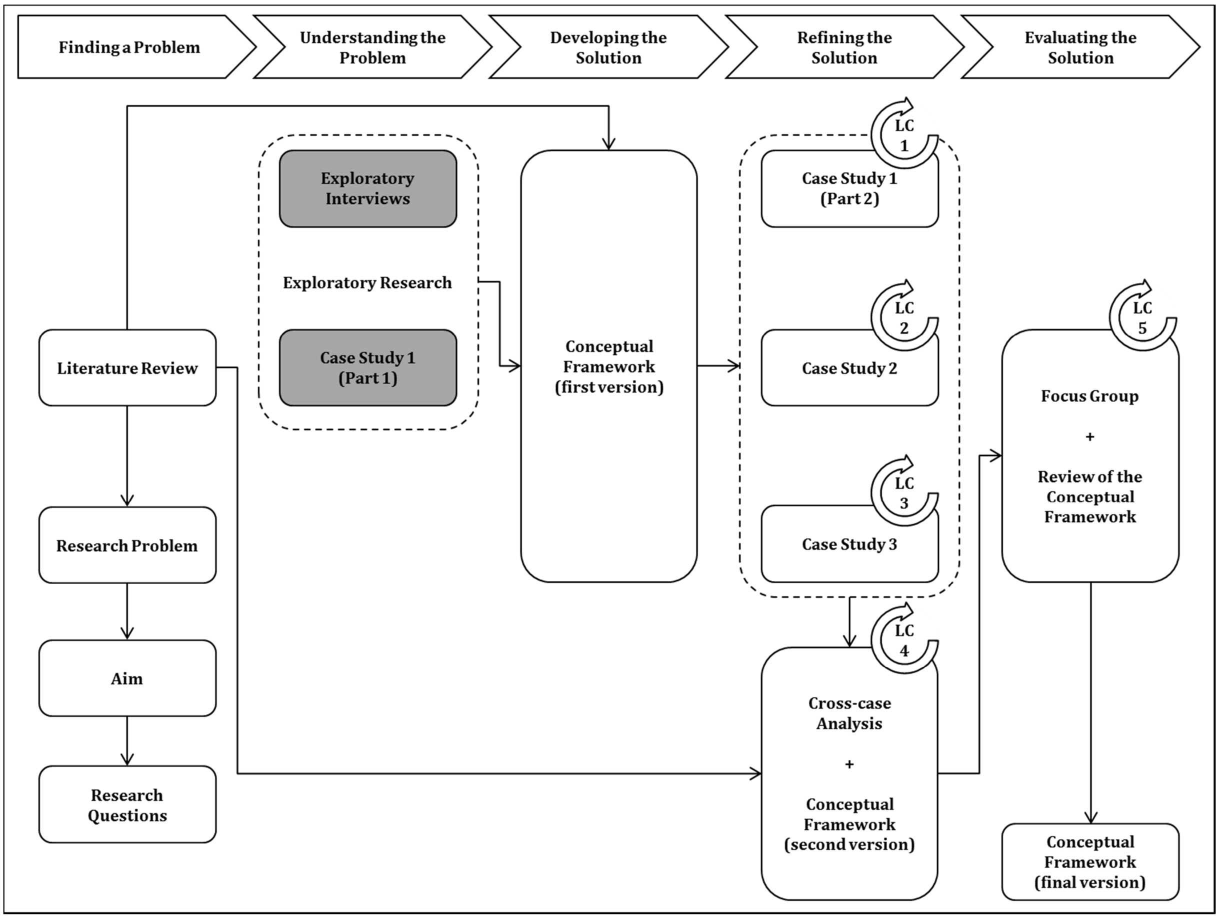


Figure 29 – Activities and developments in the 'Understanding the Problem' stage

4.1 Exploratory Interviews

A set of interviews was carried out between November 2012 and February 2013 with academics and practitioners. First, the participants were selected according to their professional and academic background. This research interviewed participants from Brazil and UK in order to gather perceptions from people in two different environments. The criteria for selecting the participants were based on their previous experience in construction projects, their understanding about construction supply chains, and their background. The purpose of the interviews was not to generalize theory from them. On the contrary, the interviews were used for collecting perceptions from the participants and put them together with findings from the literature. The participants were formally invited to take part in this research. Two of the participants were from major construction companies in the infrastructure sector, and the other three participants were from different universities. The names of the participants, companies, and educational institutions are not disclosed. Table 8 illustrates the list of exploratory interviews.

Table 8 – Exploratory interviews

Interviewee	Job Title	Academic Background	Country	Years of experience
1	Commercial Manager	BSc in Civil Engineering	Brazil	> 15
2	Professor	PhD in Civil Engineering	Brazil	> 15
3	Contract Manager	BSc in Civil Engineering	Brazil	> 10
4	Senior Lecturer	PhD in Op. Management	UK	> 10
5	Senior Lecturer	PhD in Op. Management	UK	> 5

It is the opinion of the interviewees that SCM should have a place in the strategic discussions of the top management of construction companies. Discussion with interviewees pointed out that a framework for managing construction supply chains should focus on both the project and the enterprise levels. The interviews provided an initial perception in the following topics:

a) **Perspectives regarding supply chain management:** it is the view of interviewees that there are two perspectives for managing supply chains: process and system. The process perspective expresses SCM as a process involving multiple companies and aiming at customer requirements. According to interviewees, such a view is linear and should be used for representative purposes, as SCM is not a sequence of activities but a network of them. The system perspective can be envisioned as a set of multiple companies in an entire system or in a set of sub-systems. This view is reported as not linear, and it should be applied in order to understand the variety of interactions within SCM. In addition, interviewees have positioned SCM at the strategic level of organizations, and they have indicated four high level issues to be tackled: sustainable processes, constant changes in customer requirements, the need for specific developments in ETO supply chains, and the difficulties faced by managers in envisioning the extent of their supply chains.

b) **The need for a framework for managing construction supply chains:** it is the opinion of interviewees that a contextualized framework for managing construction supply chains is required, due to the lack of developments in this area. Initially, the positive and negative aspects of SCOR and GSCF were discussed with interviewees, as they are the most well accepted process-based frameworks for managing supply chains. It was pointed out by interviewees that the positive aspects identified in SCOR and GSCF should be used as a background for developing a specific framework for the construction sector vis-à-vis the specific traits of the sector. Finally, the interviewees referred to suppliers as essential parties to be considered in ETO supply chain structures.

c) **The design of construction supply chains:** a set of areas to be considered in the development of a framework for designing (and redesigning) construction supply chains was pointed out during interviews. It was argued that construction companies have to develop customized approaches for designing their supply chains, and they should take into consideration the positioning of the decoupling point when doing so. The existence of different managerial levels (i.e. project and enterprise), multiple interfaces (i.e. numerous projects and suppliers), and extensive supplier bases in the sector was debated. Interviewees described the need for increased early supplier involvement and a more balanced power dynamics in construction supply chains. Finally, interviewees recommended the inclusion of risk management and flexible strategies when devising frameworks for construction supply chains.

d) **The improvement of construction supply chains:** interviewees reported that variability is a key issue to be tackled in supply chain improvement. The relevance of performance measurement for assessing to what extent variability exists was discussed during interviews. However, it was noted that performance measurement in construction is hard to implement due to the intrinsic fragmentation in supply chains. The evaluation of suppliers was pointed out as a current practice that needs to be reinforced. Interviewees stated that performance metrics have been used more to point out problems rather than to effectively solving them. Efforts regarding supplier development were associated with two types of initiatives: training schemes and consultancy. It is the opinion of the interviewees that a supplier's development must be monitored via KPIs, so that its outputs can be linked to the performance of the focal company in a supply chain.

4.1.1 Inputs for Developing the Framework

The following topics comprise the key inputs extracted from exploratory interviews to be considered when developing the framework:

- There are two viewpoints to be considered in supply chain management. First, there is the management view, in which SCM should be managed as a process comprising multiple organizations. Second, there is the structural view, in which SCM should be systematically interpreted as a network of organizations;
- Supply chain management does not relate with operational aspects. On the contrary, SCM should be treated as a strategic topic in the agenda of organizations;
- There is a need for contextualized SCM approaches, given that specific business scenarios have different production processes, strategies, markets, and products, among other factors;
- Features from previous developments in the manufacturing sector should be studied, adapted, and implemented when developing SCM frameworks to be contextualized in the construction sector;
- There are specific issues to be addressed in a SCM framework for the construction sector, especially those concerning design and improvement aspects of supply chains.

4.2 Case Study 1 (Part 1) – Report

In this section, the findings of an exploratory case study conducted in Company A are reported. Case Study 1 (Part 1) was conducted between May 2013 and September 2013, focussing mostly on activities for collecting and analysing information. The schedule comprised 9 consecutive weeks of conducting semi-structured interviews, participation and observation of meetings, collection of documents, and site visits among others. The selection of participants to be interviewed and meetings to be observed aimed at covering the key departments and processes in Company A with implications on its supply chain. In this sense, employees from different sites, processes, and hierarchy ranks were approached. Given the intrinsic nature of Company A, people from both project and enterprise levels were interviewed in order to capture a wider perspective from interviewees. In addition, data collected was presented and validated in a meeting with key executives from Company A.

Examples of documents collected are purchase orders, requests for proposals, and minutes of meetings. Significant insights were obtained from interviews with Project Managers and Quantity Surveyors at the Project Level, as well as from employees of the procurement department at the Enterprise Level. The observation of meetings was helpful for gathering perceptions about the business culture of Company A and its influence on the supply chain. The meetings in the Procurement and Maintenance departments are frequent, and all meetings are conducted by senior management in the respective departments. In general, a sense of urgency and lack of planning was observed in these meetings, especially because the majority of actions planned by Company A were delayed when compared to the original schedule. Table 9 presents the list of meetings observed in the procurement and in the maintenance department and

Table 10 presents a list of semi-structured interviews carried out in Case Study (Part1).

Table 9 – List of meetings observed in Case Study 1 (Part 1)

Meeting	Meeting Observed	Level
1	Procurement Department	Enterprise
2	Maintenance Department	Enterprise
3	Procurement Department	Enterprise

Table 10 – List of interviews in Case Study 1 (Part 1)

Interview	Position of the Interviewee	Level
1	Procurement Manager	Enterprise
2	Procurement Associate	Enterprise
3	Senior Quantity Surveyor 1 and Quantity Surveyor 1	Enterprise
4	Procurement Associate	Enterprise
5	Maintenance Associate 1	Enterprise
6	Maintenance Associate 2	Enterprise
7	Procurement Manager and Procurement Associate	Enterprise
8	Inventory and Warehouse Manager	Enterprise
9	Administrative Manager	Enterprise
10	Quantity Surveyor 2	Enterprise
11	Quantity Surveyor 3	Enterprise
12	Senior Quantity Surveyor 2	Enterprise
13	Quantity Surveyor 4	Enterprise
14	Senior Quantity Surveyor 3	Enterprise
15	Materials Management Associate	Enterprise
16	Materials Management Associate	Enterprise
17	Senior Quantity Surveyor 1	Enterprise
18	Quantity Surveyor 1	Enterprise
19	Storeman	Project
20	Senior Quality Associate	Enterprise
21	Information Technology Associate	Enterprise
22	Operations Director	Enterprise
23	Administrative Director	Enterprise
24	Finance Director	Enterprise
25	Quantity Surveyor 5 and Storeman	Project
26	Regional Project Manager	Project
27	Project Manager	Project
28	Maintenance Manager	Enterprise
29	Regional Project Manager	Project
30	Human Resources Manager	Enterprise
31	Information Technology Manager	Enterprise
32	Commercial Manager	Enterprise
33	Site Manager	Project

In addition, eleven tier-1 suppliers of Company A were approached in this research as listed in Table 11. The list of suppliers to be approached in this research was provided by Company A considering: financial impact, location, overall performance, and time limitation for completing the case study. Suppliers were formally contacted in advance in order to arrange dates for the interviews and site visits (where applicable). The suppliers approached in this research have a long-term relationship with Company A (10 years on average). Senior employees were appointed by the suppliers as interviewees, which provided a wide set of information. Interviews were recorded and summarized in order to support the findings emphasized in this research.

Table 11 – List of suppliers approached in Case Study 1 (Part 1)

Supplier	Market Sector	Number of Employees	Position of the Interviewee	Site Visit
1	Heavy equipment (trucks)	249	Commercial Manager (2)	Yes
2	Precast concrete tubes	450	General Manager	Yes
3	Precast concrete box culverts	15	General Manager	Yes
4	Diesel fuel	9,600	Commercial Associate	Yes
5	Heavy equipment (excavators)	989	Commercial Manager	Yes
6	Heavy equipment (excavators)	292	Commercial Manager	Yes
7	Asphalt	199	Commercial Director	Yes
8	Specialty parts for equipment	12	Commercial Director	Yes
9	Asphalt	8	Commercial Manager (2)	Yes
10	Drilling and blasting materials	1,100	Commercial Manager	No
11	Personal protective equipment	30	Commercial Director	No

4.2.1 Characteristics of Company A

Company A is a major construction company in Brazil. It is focused on infrastructure projects such as tunnelling, earthworks, and highways construction. All projects are geographically distributed throughout Brazil, usually in remote locations, and they are managed independently from each other by local Project Managers. Suppliers send materials and mobilize crews directly to the sites, which has implications in converging logistics flows.

Figure 30 illustrates the distribution of existing project sites in Company A. The numbers located on the side of the figures in the map indicate the quantity of project sites in a particular area. In addition, the approximate location of Company A’s headquarter is indicated on the map as ‘HQ’.

Figure 30 – Location of project sites in Company A

The projects are characterized as one-of-a-kind, given that such projects are developed under an ETO production strategy. In this sense, the company manages its projects based on real demand from the early design stage.

The company's operations are based on two central processes, namely Sales and Production:

- **The Sales process** represents all commercial efforts, ranging from the quest for new projects, preparation of proposals for bidding, and its relationship with customers. The main actors of the Sales process are the Sales Director and the Bid Manager;
- **The Production process** comprises all construction activities and provision of resources to the concurrent projects. The key actors of the Production process are the Production Director, the Maintenance Manager, and the Project Managers.

The remaining internal processes (i.e. Taxes, Information Technology, and Procurement, among others) work as support for Sales and Production. Research efforts were concentrated in the **Procurement process**, which has multiple interfaces with other internal processes, especially Production.

4.2.2 Supply Chain Management in Company A

Company A has 24 employees directly involved in procuring four categories of items, and several other personnel (i.e. interns, analysts) acting as back office. People in the procurement process overlook all projects in Brazil, although some buyers and quantity surveyors may be allocated in specific project sites. The criteria for allocating procurement specialists in a particular project are based on the complexity of the projects and in the availability of people to be transferred. Roughly, 30% of the annual revenue of Company A (£60 million) is annually spent in the purchasing of four different categories as shown in Table 12.

Table 12 – Procurement spend per category in Company A

Procurement Category	Annual Spend	Percentage
Materials	£33 M	55%
Services	£12 M	20%
Heavy Equipment and Vehicles	£12 M	20%
Equipment Rentals	£3 M	5%
TOTAL	**£60 M**	**100%**

The procurement categories are organized as follows:

a) **Materials** comprises all items to be supplied to the construction sites such as grit, concrete, sand, asphalt, explosives, drill bits, health and safety equipment, parts and components for equipment and vehicle maintenance, among others, which are grouped into 72 different categories. Company A purchases Materials from 2,265 different suppliers and the majority of them are located in Brazil.

b) **Services** include all types of activities outsourced to other companies such as construction design, technical consultancy, and explosion experts, among others, which are not grouped into families. Currently, Company A has 1,456 different service providers in its supplier base.

c) **Heavy Equipment and Vehicles** are purchased in order to renew and expand the fleet of Company A. Such equipment and vehicles comprise mining trucks, grit crushers, drill rigs, hydraulic excavators, and tractors, among others. Company A owns a wide range of vehicles and equipment, which results in significant maintenance costs given the rough operational conditions. Currently, Company A has 291 suppliers in the Heavy Equipment and Vehicles category.

d) **Equipment Rentals** comprise the smaller part of its procurement categories. Equipment is rented when there is increased demand in the construction sites and reduced availability of equipment and vehicles owned by the company due to maintenance or production. Presently, Company A negotiates Equipment Rentals with 229 different suppliers in Brazil.

In order to have a better understanding of the procurement process in Company A, a value stream mapping exercise was carried out. Such an approach permitted the construction of the process map and provided the basis for a discussion regarding the entire Procurement process. Two senior representatives of Company A took part in the exercise, which is illustrated in Figure 31.

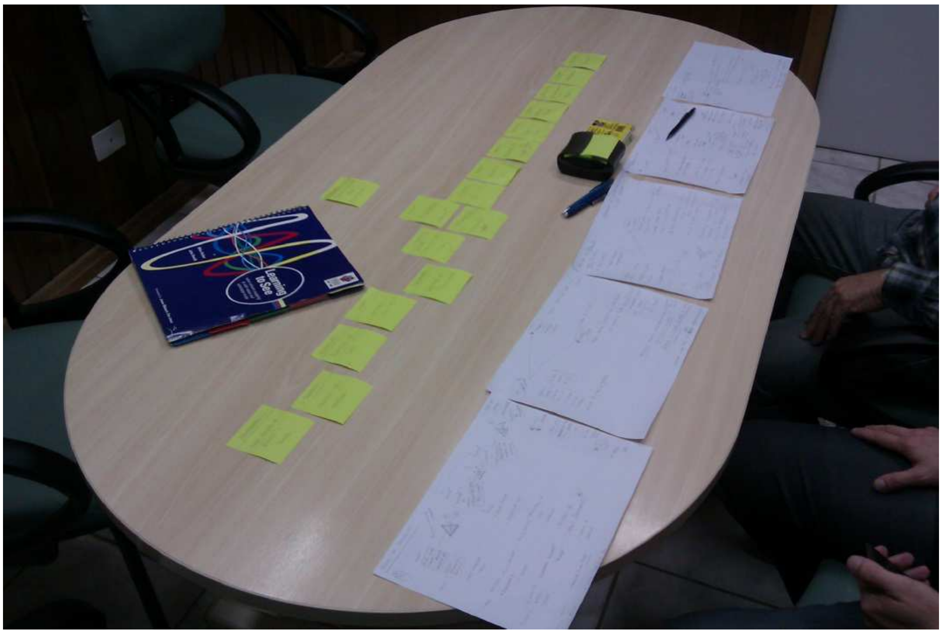


Figure 31 – The development of a value stream map in Case Study 1 (Part 1)

Different types of waste were identified in the Procurement process:

- **Poor specification** in Request for Proposals (RFP) and consequently in Purchase Orders (PO) was reported as a common problem. There is a high level of RFPs containing incomplete or erroneous information, a lack of technical drawings for specialty parts, and out-of-date manuals and technical guides, among others. During the exercise, the impacts of poor specification as a main cause for increased rework were discussed. Currently, Company A does not tracks or measures rework in RFPs or POs;
- **Delayed approvals** of RFPs and POs were conveyed as an issue. Company A has an approval system for RFPs and POs that comprise different hierarchical levels (i.e. supervisors, site managers, project managers, directors). Although this system is electronically based, there is increased waiting time for such approvals,

which ultimately can affect project delivery. Company A does not track or measure delayed approvals in terms of time or incidence;

- **An excessive number of RFPs and POs** were found in Company A. Data referring to the period between January 2012 and June 2013, concerning the procurement category of materials, indicated that 4,000 RFPs on average are created every month. Interestingly, for the same period, 4,000 POs on average are generated every month. Such data suggest that RFPs are not analysed and consolidated before POs are generated for suppliers. There is a lack of awareness regarding the increased indirect costs (i.e. transactional costs) associated with PO generation. Company A does not track or measure the number of POs, RFPs, their impact on indirect costs, and possible economies of scale to be generated;
- **Restricted information technology systems and dated procedures** were found in Company A. RFPs are registered in the system and suppliers are invited for bidding via an e-mail containing specifications. The internal guidelines of Company A mandate that prices and commercial conditions of three suppliers be consulted for each RFP. Suppliers return their prices and formal quotations by replying to the original e-mails sent by Company A. After that, prices are registered in the system for comparison purposes. Next, a PO is placed to a particular supplier, which is responsible for providing the corresponding material or service. Due to poor IT reliability, people in the procurement department have to phone suppliers to double check whether they have received the POs accordingly. In addition, internal regulations mandate that POs, RFPs, and respective quotations be printed and archived. This process is repeated 4,000 times a month on average only in the procurement department. People allocated in warehouses, which are responsible for receiving and storing materials, print and archive the same information. These procedures have never been reviewed since their implementation, although all printed information is electronically archived. Vis-à-vis the issue in sending and receiving POs, representatives from the IT department confirmed that a solution should be installed in a newer version of the system used by Company A. Meanwhile, 4,000 phone calls per month are placed to check whether POs were transmitted.

After identifying different forms of waste in the procurement process, specific topics regarding supply chain management in Company A were widely examined with different buyers, procurement specialists, procurement managers, directors, and suppliers:

a) There is **reduced outsourcing** in Company A. The company opted for a self-delivery strategy, in which Company A has ownership of all equipment and vehicles involved in the activities on sites. In addition, labour is not outsourced either. Renting equipment and vehicles is reported as rare, and it happens only for levelling production capacity on a temporary basis. Therefore, there are impacts in the maintenance department derived from the strategy adopted by Company A. By owning the equipment, Company A has direct and indirect costs associated with transporting, managing, maintaining, and repairing its private fleet of heavy equipment and vehicles. Even though Company A has projects throughout the country, all equipment is directed to the maintenance area in Company A's headquarter. Ultimately, such a strategy impacts on the procurement department, given that specialty parts and services should be procured in order to meet maintenance plans and urgent repairs.

b) A number of **rushed purchase orders** were identified. Interviewees reported that production planning is not integrated with the procurement department. Although Company A carries out project planning regularly, relevant information for procuring materials and services (i.e. bills of materials, quantity take-offs, production schedules) are not available at the right time. In many cases, interviewees reported that such information is accessible only three months after a project has already started work on site.

c) There are **limited cross-functional activities**. There is a lack of integration between the areas responsible for bidding projects, procuring materials, and planning and operating production. The key variable, considered by Company A top managers after they win a bid, is the promptness of mobilization. There is a critical thread of information that connects bidding through procuring to planning and operating projects. Although Company A has a good reputation in the market for starting works on site quickly, there are a number of side effects: increased costs and reduced margins, project delays, and poor quality, among others. In addition, by not integrating cross-functional activities, the pipeline visibility of future projects is limited and information is not shared internally.

d) There is **limited performance measurement** regarding Company A's supply chain. In the research process, a set of only three KPIs for managing suppliers was found in Company A: Rushed Orders, Actual Costs vs Planned Costs, and Processing Time. However, there is a lack of metrics considering operational aspects of suppliers such as delivery performance and quality performance. Interviewees showed a low level of awareness regarding poor operational performance of supply chain and its potential impacts on project delivery, and ultimately in the overall results of Company A. Non-conformances are not registered and treated formally via action plans.

e) The task of managing Company A's supply chain is based on **price-driven decisions**. The company has a large supply base, which contains more than 4,200 active suppliers. It was not found to have any structured categorization of its supply chain, apart from the four procurement categories previously presented. Relationships with suppliers are ad-hoc, and they were described during interviews as merely transactional. The selection of suppliers encompasses a risk assessment considering legal and financial aspects, and operational risks (i.e. capacity, delivery, quality) are not considered.

4.2.3 Inputs for Developing the Framework

The following topics comprise the key inputs extracted from Case Study 1 (Part 1) to be considered when developing the framework:

- Characteristics of construction companies reported in the literature were found in Company A. The key points regarding project-based production system, multiple and concurrent projects, dispersed site locations, and uniqueness of schemes were verified in practice;
- Characteristics of construction supply chains discussed in the literature were also observed in Company A. The key points concerning project-based chains, network design, interfaces, supplier base, fragmentation, and demand forecast were confirmed in the study;
- There are different types of waste in construction supply chains. Findings of this exploratory study focused on those generated by poor specifications, delayed approvals, an excessive number of RFPs and POs, and bureaucratic and dated procedures. Although there are non-added value activities, the awareness

regarding wastes and their impact on the company's performance was found to be very limited;

- The level of outsourcing produces significant influences on supply chain management. Company A presents reduced outsourcing, given the company has chosen a self-delivery production strategy. However, a high level of procurement activities are necessary due to maintenance and repair of heavy equipment and vehicles;
- Limited integration of planning activities generates increased rushed orders. Consequently, rushed orders lead to cost overruns and eventual production disruptions. Bills of materials, quantity take-offs, and production schedules should be integrated in procurement scheduling;
- There is a thread of information that should connect bidding through procuring to planning and operating projects, which is not properly linked in Company A. By not combining cross-functional activities, Company A has a limited pipeline visibility of future projects, which affects procurement planning;
- The lack of balance in performance measurement in Company A negatively impacts supply chain management. Existing metrics are not balanced, and there is no awareness regarding poor operational performance of the supply chain and its potential impacts on project delivery;
- Price-driven decisions generate ad-hoc and transactional relationships with suppliers. Ultimately, these decisions foster the adoption of large supplier bases, which have substantial administrative costs. In addition, when the criteria for selecting suppliers are limited to financial risks, the entry barriers are levelled lower.

5 DEVELOPING THE FRAMEWORK

The development of the first version of the framework is carried out in this chapter, as illustrated in Figure 32. This version comprises two central underpinnings. First, ETO construction supply chains are conceptualized in terms of their parties, levels, types of flows, and interfaces. Second, such a conceptualization is used as a background to position the existing supply chain problems. After problems are positioned, a set of best practices is proposed in order to tackle them over time.

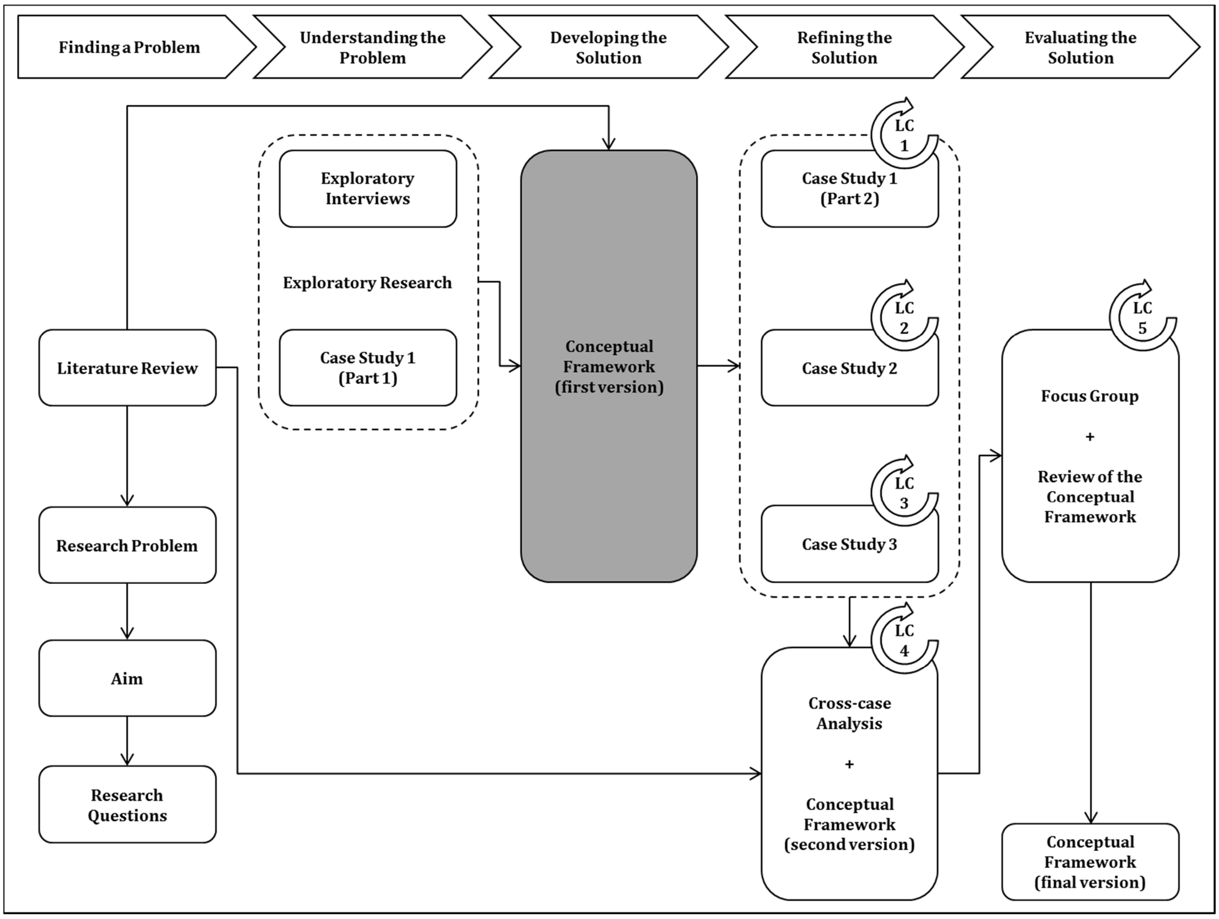


Figure 32 – Activities and developments in the 'Developing the Solution' stage

5.1 Conceptualization

Construction companies have a project-based production strategy. The project is the basic unit of production, given that all construction activities are site-based. A project, identified as 'P' in Figure 33, has different 'two-way' interactions with other parties. From the SCM point of view, a project interacts essentially with suppliers and with the business level of the construction company. The tier-1 suppliers are classified into two kinds, materials and services. Moreover, the business level is also named as Enterprise Level.

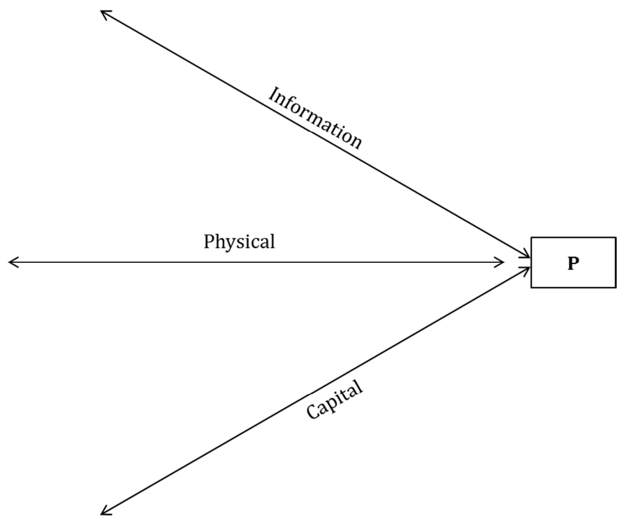


Figure 33 – A project and its interactions in construction supply chains

Considering that the focus of this research is on supply chain management, the aforementioned interactions are encapsulated in three types of flows: information, physical, and capital. During the existence of a project, one can observe numerous interactions between a project and other parties via the three flows. Such interactions are essential for the project's completion and delivery by the project team. Interactions are exemplified as follows:

- **Interactions related to the flow of information** comprise request for proposals, purchase orders, e-mails, phone conversations, and meetings, among others;
- **Interactions associated to the physical flow (materials and services)** comprise the actual delivery and mobilization of materials, parts, crews, and equipment;

- **Interactions regarding the flow of capital** encompass actual invoices, and wire transfers, among others.

A supplier, represented as 'S' in Figure 34, also has a number of 'two-way' interactions with the Enterprise Level and the different projects in a construction company. As the opposite of projects, the flows in this case diverge from suppliers to the other parties in a construction supply chain.

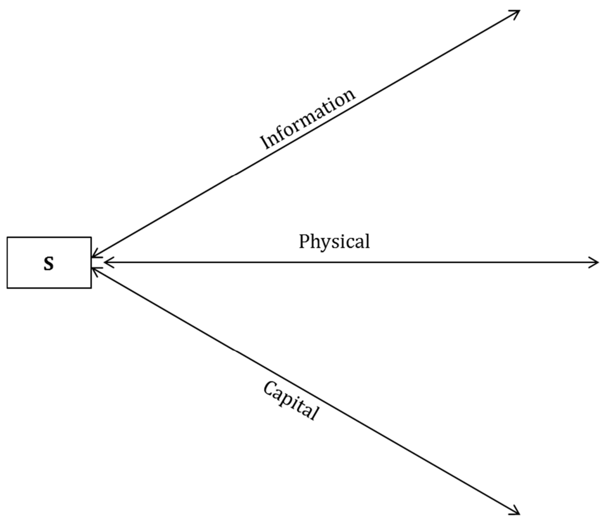


Figure 34 – A supplier and its interactions in construction supply chains

Considering the Enterprise Level of a construction company, this level is connected both to suppliers and to projects. A simplified scenario, in which a company has one supplier and a single project, is represented in Figure 35. In this scenario, the Enterprise Level interacts with the supplier by exchanging information, receiving materials and coordinating crews, and transferring capital and relevant financial information. Additionally, the Enterprise Level is interrelated with the project as well. In such a simplified scenario, it can be concluded that the enterprise level acts like a liaison between the supplier and the project.

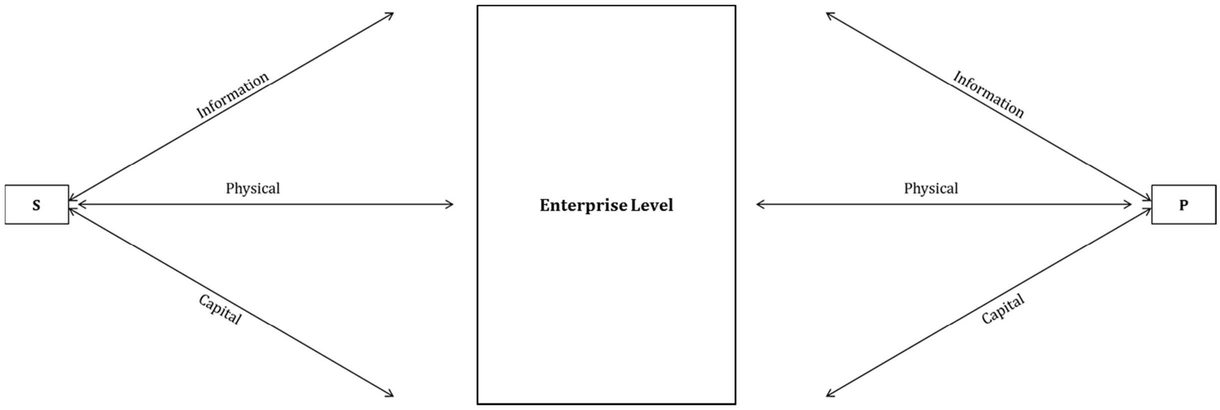


Figure 35 – A simplified view of a construction supply chain

Construction projects have long life cycles, especially those in the infrastructure sector. For example, the typical project duration reported by Company A ranges from 24 to 36 months on average. During a complete cycle of one project with a single supplier, which is a simplified view of a construction supply chain, there are numerous interactions between the parties involved.

However, the existence of multiple and concurrent projects in construction supply chains is well known. Company A reported the existence of 26 projects and more than 4,200 active tier-1 companies in its supplier base. On average, each scheme in Company A has 200 different suppliers during its life cycle. A project has specific demands and issues to be addressed, which vary from one project to the other. There are supply decisions to be made at the Project Level, given its autonomy as units of production are overseen by project managers.

By having multiple and concurrent projects, it is logical that part of the interactions with suppliers occur at the Enterprise Level and some of them happen at the project level. Different factors regarding the interactions such as their quantity, criticality, and relevance influence how suppliers, projects, and the business level interact. First, it is very difficult at the Enterprise Level to transact all interactions as the number of projects increases. In addition, as projects are one-of-a-kind, their duration and technical requirements vary. Second, the level of criticality regarding the interactions between projects and suppliers is very specific, and it differs depending on how urgently information should be available or materials should be delivered. Finally, some of the interactions might be more important to a particular project (i.e. the project is delayed due to difficult weather conditions affecting the access to the site).

An initial view of a construction supply chain is discussed and represented below. Suppliers ranging from 1 to 'n' are represented as S1, S2, and Sn. Projects ranging from 1 to 'm' are represented as P1, P2, and Pm. The Enterprise Level is positioned at the centre of Figure 36, having the role of the focal company of the construction supply chain. The flow of information is represented as 'I', the physical flow as 'P' and the flow of capital as 'C'. In this representation, one can realize the existing interfaces between suppliers and the Enterprise Level, and between the Enterprise Level and the projects.

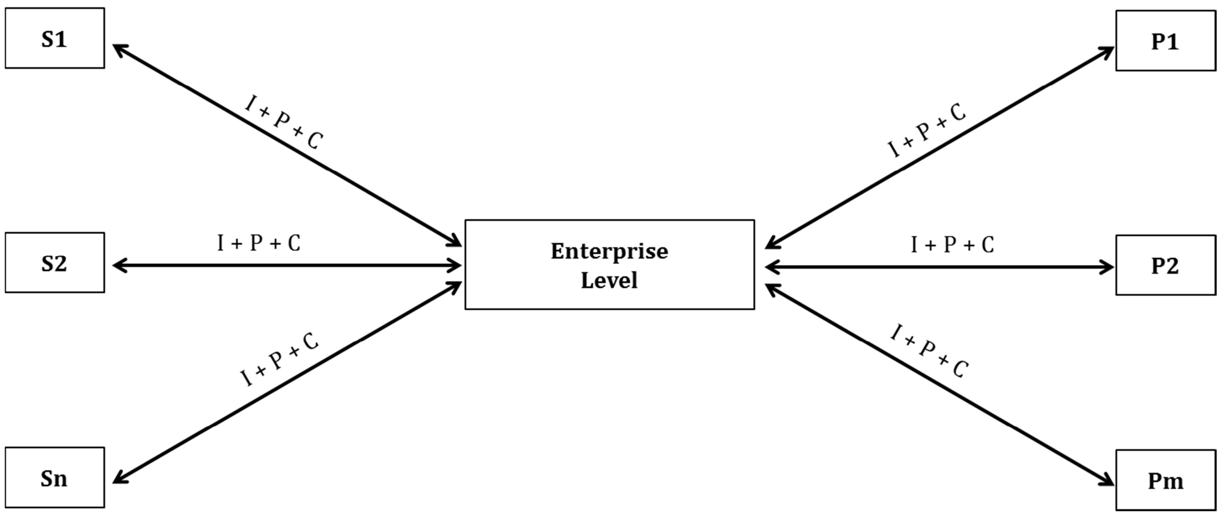


Figure 36 – An initial view of a construction supply chain

Given that suppliers and projects have significant interactions, an interface connecting them is required. Figure 37 provides an illustration of how the initial view of a construction supply chain evolved in this research. Suppliers (S1, S2, and Sn) are grouped in a single element, called 'Supplier Level'. In addition, Projects (P1, P2, and Pm) are grouped in an element called 'Project Level'. Therefore, two additional levels are now emphasized in conjunction with the Enterprise Level.

It should be observed that there is a shift in the positioning of the enterprise level. Given that there are increased interactions between the Supplier Level with the Project Level, the Enterprise Level is moved upwards, as indicated in Figure 37. In addition, the Supplier Level and the Project Level are moved closer to each other. It is the understanding of this research that such positioning provides a better representation of the interactions in a construction supply chain.

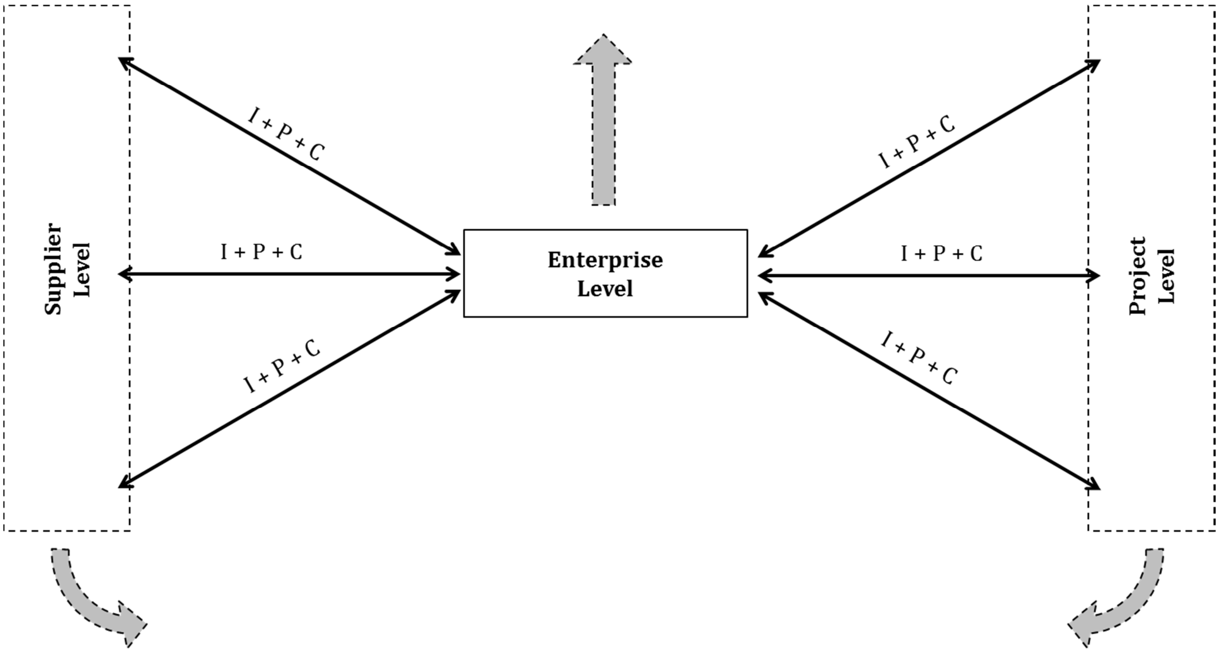


Figure 37 – A second view of a construction supply chain

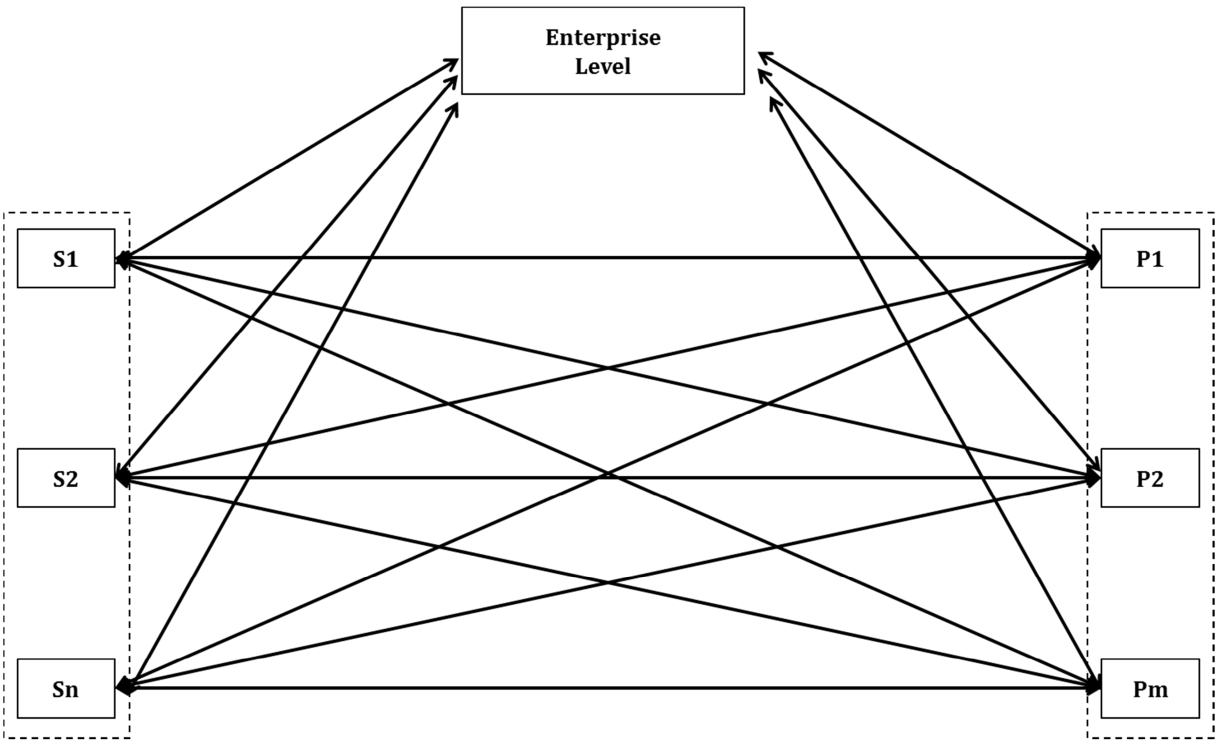


Figure 38 – Interactions in a construction supply chain

In Figure 38, a set of possible interactions between 'n' Suppliers in the Supplier Level, 'm' Projects in the Project Level, and the Enterprise level is illustrated. Although the interactions presented above are not named individually in Figure 38, the interactions represent the aforementioned three types of flows. A different balance between the three levels, given the numerous interactions between the Supplier Level and the

Projects Level is suggested. Therefore, all parties and the connecting flows have similar relevance in the proposed conceptualization.

Apart from the flows discussed earlier, it is important to understand the interfaces between the three aforementioned levels. Although these levels exist, as projects are managed on an autonomous basis, it can be argued that the roles across the different levels vary in terms of the tasks concerning SCM. Evidence from Company A demonstrated that a part of the decision-making is concentrated at the Enterprise Level, and the remaining part at the Project Level. Even though these levels are in the same organization, many internal conflicts were detected between them (i.e. production procedures and procurement policies not followed at the Project Level).

Three interfaces are proposed for conceptualizing construction supply chains. The interfaces are defined as follows and are represented in Figure 39.

a) **(Interface A) Enterprise Level - Project Level:** is the boundary at which the contractor manages multiple and concurrent projects, usually geographically dispersed. In addition, such projects are typically one of-a-kind and they demand a wide range of materials, high-skilled workers, and diverse resources to be allocated at the project site. In addition, projects have a temporary nature and contractors tend to have a pipeline of upcoming projects, which requires the continuous conception of new supply chains.
b) **(Interface B) Enterprise Level - Supplier Level:** is the interface at which the contractor manages multiple suppliers from the enterprise perspective. Construction companies have permanent and temporary suppliers, which should be managed in different ways. From this viewpoint, contractors need to establish a long-term view for managing suppliers in the long run, aiming at strategic objectives for improving the supply chain.
c) **(Interface C) Project Level - Supplier Level:** is the boundary at which the contractor manages suppliers from the project perspective. At this level, construction companies have to cascade enterprise policies, procedures and guidelines for the project level, manage permanent suppliers, and coordinate temporary suppliers. Such coordination must occur at the project level, since temporary suppliers will be used only in particular projects, mostly because of their location and their technical capabilities.

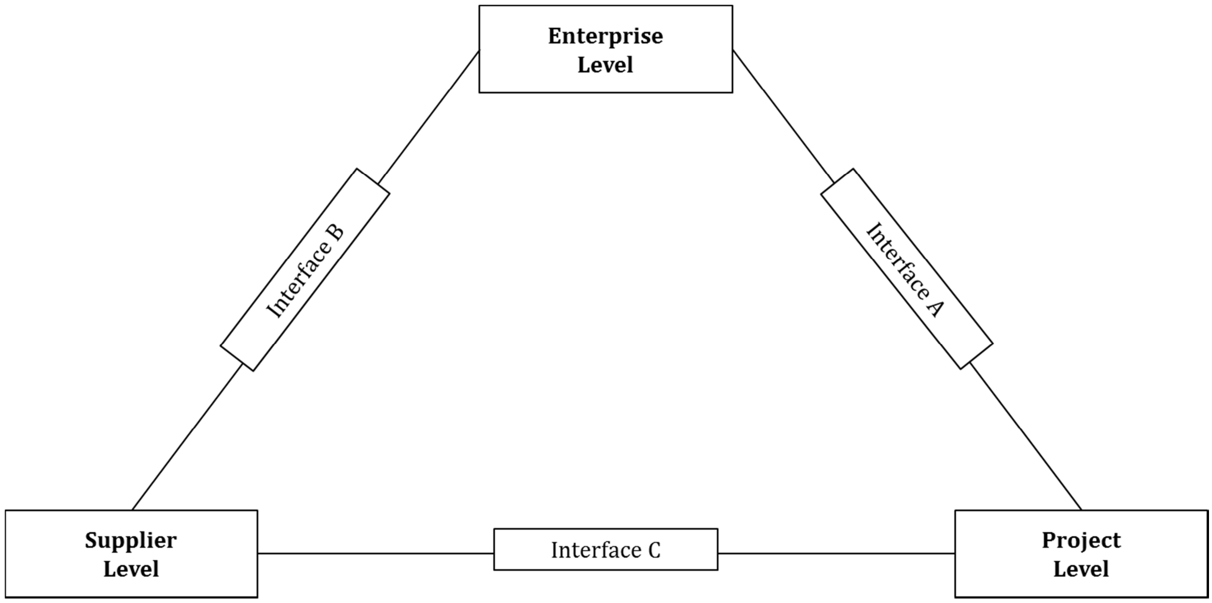


Figure 39 – The interfaces of construction supply chains

The three types of flows have a different relevance and intensity as they are linked to the proposed interfaces. A conceptual view of construction supply chains is then presented in Figure 40. In this view, the interfaces and flows can be characterized as follows:

- **Interface A is mainly concerned with the Information flow**, which is critical for the entire supply chain, given that information from projects is the main input for planning subsequent processes and activities (i.e. purchasing, producing, and delivering). The major challenge in managing Interface A is to aggregate information from projects, once construction companies tend to give managerial autonomy for the projects. Managerial autonomy at project level has one major drawback: fragmented information. Such a drawback leads to poor synergy and decreased integrations between projects. Once information flow at Interface A is improved, the level of uncertainty is decreased from projects to enterprise to suppliers. Decreased uncertainty contributes to reducing inventories, rushed orders, and ultimately costs;
- **Interface B is mostly focused on the Information Flow and Capital Flow**, based on inputs from the projects. Purchase orders, shipping instructions, and payment reports flow via Interface B between the enterprise and suppliers. The major challenge in managing Interface B is to provide qualified and on-time information for suppliers. It is known that construction companies tend to place an increased amount of rushed and imprecise orders to their suppliers;

- **Interface C is mainly concerned with the Physical Flow and the Information Flow**. Materials are delivered at project sites according to order conditions, and they should comply with technical specifications, delivery and quality performance, and packaging requirements. Suppliers mobilize their crews and equipment directly to sites as well. The information flow at Interface C should be managed as a communication channel for coordinating activities at the project site, since unexpected conditions may require changes (i.e. delivery details, changes in packaging, instructions for loading and unloading lorries, product returns).

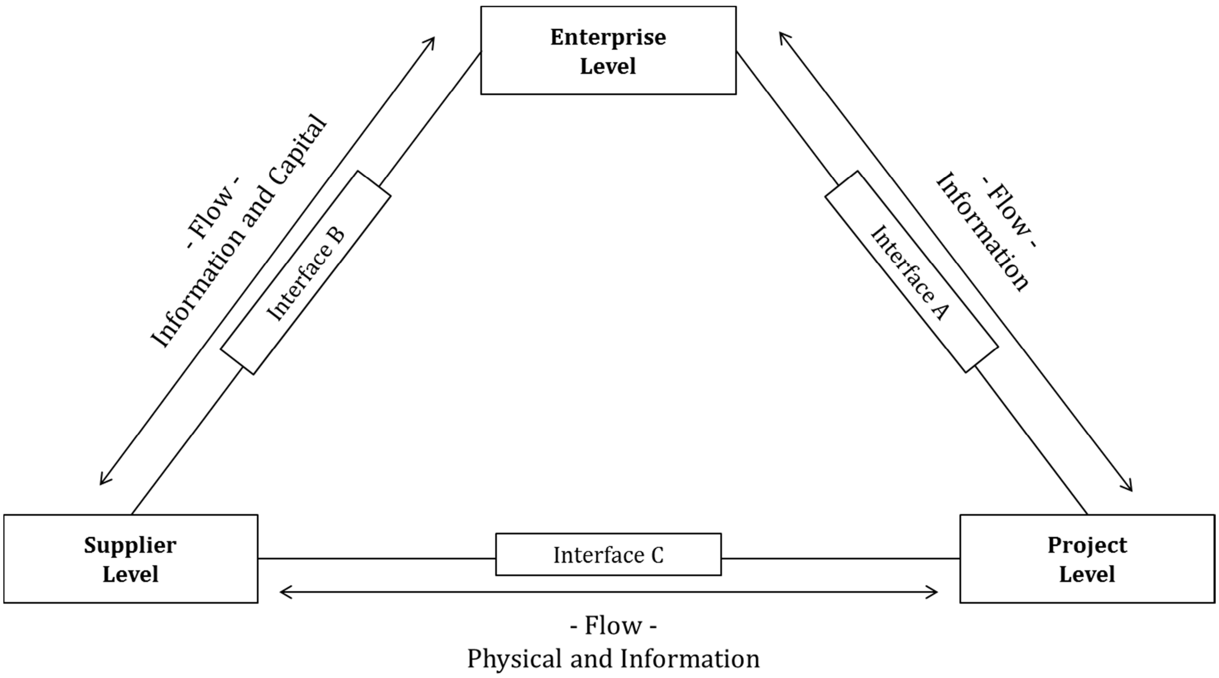


Figure 40 – A conceptual view of construction supply chains

The conceptualization of construction supply chains herein proposed takes into account a set of inputs from the literature of supply chain management. The traditional view of supply chain management presented in the SCOR and GSCF models was studied and adapted so that it could be adopted. It is worth mentioning that the conceptual view of a construction supply chain developed in this research does not rely on a single focal organization in all relationships between suppliers and projects. On the contrary, the proposition of this research rebalances the supply chain by acknowledging that direct interactions between suppliers and projects are essential. In this case, new links connecting supply flows were then encapsulated in three interfaces. By adopting such view, there are three focal levels in the conceptual view and not just one: Enterprise Level, Supplier Level, and Project Level.

5.1.1 Locating the Problems of Construction Supply Chains

By understanding the different levels of construction supply chains and the interfaces between them, it is possible to position problems accordingly. As discussed in the literature review, construction supply chains typically present a number of problems at their interfaces. Examples of these problems reported by Luhtala *et al.* (1994) include rushed orders, incomplete order specifications, long order processing times, lack of synchronization in components delivery, variability in delivery times of components and pre-assembled modules, and last-minute changes in schedule and specifications requested by customers. Discussions were carried out with Company A representatives, in which problems were identified and positioned as indicated in Table 13.

Table 13 – Problems found in Company A

Interface	Information	Capital	Materials
A	Increased RFPs Rushed RFPs Rework in RFPs Poor evaluation of suppliers	N/A	N/A
B	Delayed reply of RFPs Rework in RFPs Increased POs Rushed POs Rework in POs Poor IT reliability in transmitting POs Poor selection of suppliers Expansive supplier base Limited tracking of POs Limited feedback to suppliers	Delayed approval process of POs POs released to suppliers prior to internal approval Rework in invoices Stressful negotiations Reduced economies of scale Poor IT reliability in transmitting invoices Delayed payment of suppliers	N/A
C	Limited information about suppliers' performance Limited synchronization with site scheduling	N/A	Increased transportation damages Poor delivery performance Poor quality performance

In this view, the problems identified in Company A are examined in each interface as follows:

- **The Information Flow at Interface A** was examined. A large number of Requests for Proposals (RFP) from the project sites were observed in Company A. The number (4,000 RFPs of materials per month on average) was perceived as too high because it approximately corresponds to the same amount of Purchase Orders (PO) of materials. This certainly indicates a problem, because it shows that RFPs are not planned appropriately: it was found that many POs for the same items were placed to suppliers without aggregating internal demand. In addition, RFPs classified as rushed reached 33% on average. Company A does not measure RFPs rework, but it was found that there are a large number of RFPs that are "typically fixed or adjusted" in order to comply with internal procedures. Finally, the project sites provide a poor or non-existing evaluation of suppliers to Company A;
- **The Information Flow at Interface B** was investigated. It was found that there is too much waste at this interface due to waiting for a delayed reply to RFPs. In addition, there is also increased rework in RFPs caused by poor specifications. Again, Company A does not measure rework or time wasted in waiting for delayed reply to RFPs. Due to the reasons previously discussed, an increased number of POs of materials was found (4,000 POs per month on average), and 33% of them were classified as rushed on average. Rework of POs is perceived by Company A 'as common', and they do not have measures for it. In one meeting, the procurement team estimated that 50% of the POs require rework due to poor reliability in transmitting information to suppliers. In this sense, quantity surveyors and buyers of Company A have to double check by phone whether or not the suppliers have received their POs, producing high levels of hours of rework. Limited tracking of POs and provision of feedback to suppliers was also found. Suppliers are poorly selected, and there is no structured method for qualifying future suppliers according to a pre-defined set of specifications. Finally, Company A has an extensive supplier base comprising more than 4,000 active suppliers. Company A has limited awareness about the potential impacts of large supplier bases, namely increased indirect costs, and decreased strategic alignment, among others;

- **The Capital Flow at Interface B** was explored as well. Although the flow of capital has indirect impacts on the supply chain, many problems were found in this flow. First, many orders were delayed because of waiting in the approval process. Company A defined a specific financial range that requires orders above the range to be approved by managers and directors depending on their total amount. Although this practice is quite standard in the market, if the approval process does not occur as expected severe delays are realized. In addition, another problem was found due to the approval processes: in many cases, orders are released to supplier's prior to internal approval in order to 'expedite' the process. Many suppliers reported how inappropriate such practice is for their business, given that it increases uncertainty in the supply chains. Rework, poor IT reliability for transmitting invoices, and delayed payment of suppliers was also found in the flow of capital. Time consuming and stressful negotiations were also pointed out by Company A as a 'typical' problem. Finally, reduced economies of scale were observed in the company;
- **The Information Flow at Interface C** was studied. Company A keeps limited information about the performance of suppliers. In general, this limitation was attributed to the 'informality' and 'speed' in which inventory and warehouse staff tend to solve problems. Poor synchronization between suppliers and project site scheduling was observed;
- **The Physical Flow at Interface C** was analysed. Overall, this interface presented significant problems in the service level: transportation damages, poor delivery and quality performance. Nevertheless, the major highlight was the lack of awareness about problems at this interface. Limited performance measures were found.

5.2 Practices

Given the existence of problems at the interfaces of construction supply chains, a systemic approach to tackle such problems deserves consideration. The construction supply chain is in constant change. On the one hand, construction companies have to conceive and adapt their supply chains for the upcoming projects all the time, as an intrinsic characteristic of their business. In this sense, there is a continuous concern regarding the design and redesign of the supply chain. On the other hand, construction companies have to improve their supply chain capabilities for increasing the performance of project delivery, and ultimately their competitive advantage.

As the design and improvement of construction supply chains is not a one-day job, a structured and systemic solution is required, given problems can be treated but in the future new ones will appear naturally. The systematic approach proposed is composed by a set of best practices to be adopted by construction companies.

A set of best practices, particularly selected and adapted from the literature, is initially proposed for supporting the design and improvement of construction supply chains. It is the understanding of this research that design and improvement implicate directly in the operation and control of production systems. Therefore, it makes sense to devise practices focused on these principles in order to obtain enhanced results in operation and control. The choice of practices to support construction supply chains was motivated by the following factors:

- **Practices are not a 'one-time thing'**. On the contrary, they should be adopted, repeated, and extended as a permanent management initiative;
- **Practices are not 'one size fits all'**, which means that they need to be developed considering the characteristics of a particular context;
- **Practices support long-term development**, which complies with the viewpoint of this research: construction supply chains should be managed on a temporary basis only at the project level. However, at the enterprise level there should exist a longstanding management perspective supported by practices;
- **Practices involve multiple parties in a supply chain**, given that they could be adapted and then adopted widely;
- **Practices should be reviewed systematically.** This is a positive aspect, given the constant changes in the business scenario. By revising the practices periodically, they would incorporate new external inputs on a regular basis.

In this sense, the proposition of practices is divided into two types: those concerned about design and those focused on improvement, as illustrated in Figure 41.

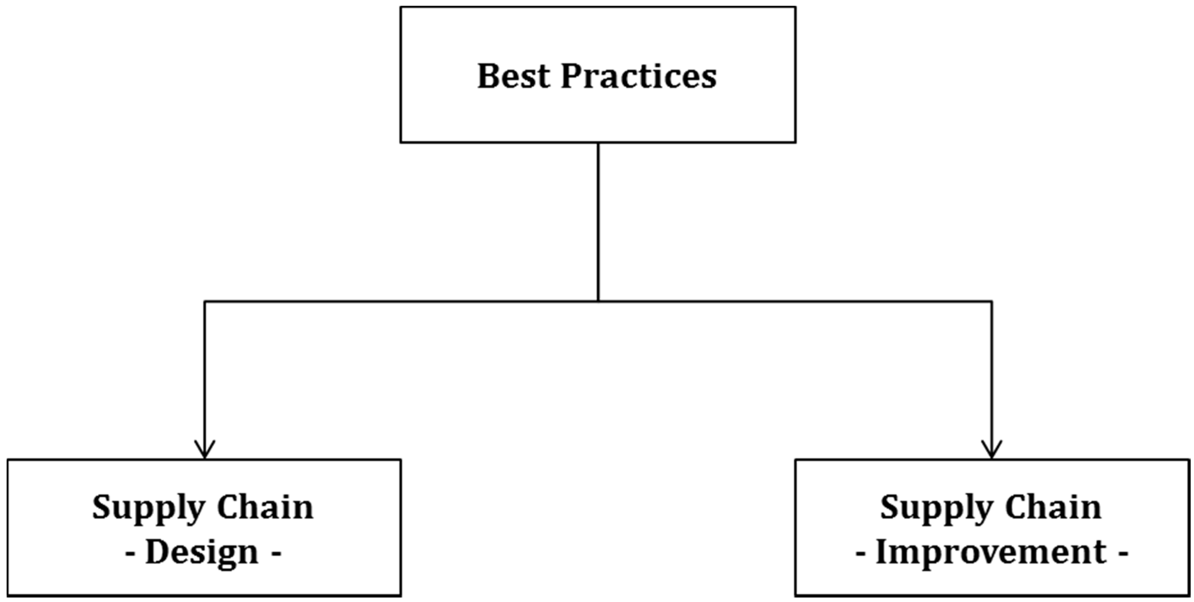


Figure 41 – Best practices and their context

Preliminary practices for designing and improving construction supply chains are listed in Table 14.

Table 14 – Summary of Practices (first version)

Practice	Interface	Type
Supply Chain Risk Management	B	Design
Flexibility Management	C	Design
Supplier Relationship Management	B	Improvement
Performance Measurement and Benchmarking	C	Improvement
Improvement Planning	A	Improvement

5.2.1 Practices for Designing Construction Supply Chains

Construction companies need to conceive new supply chains constantly. Every new project is located in a different region, demands specific materials and work force, and requires a contextualized approach for conceiving its arrangement. The following practices were investigated in the literature and they are initially recommended for supply chain design.

5.2.1.1 Supply Chain Risk Management

Risk Management is proposed as a practice to tackle problems and to improve the relationships at Interface B. Previous research in this field was evaluated and adapted in a set of items, which are depicted in Table 15.

It is a common mistake in companies to consider only financial and operational risks. In many cases, there might be other typologies of risks such as those related to legal and cultural aspects. The consideration of a wide typology of risks, which should be applied in multiple tiers of the supply chain when appropriate, is recommended. The identification and categorization of all risks is also suggested. The risks should be then cross-referenced with the sources of uncertainty identified. The calculation of the time to recover from disruptions for a particular material or supplier is advised in order to measure its impact for prioritization purposes. The strategic allocation of buffers and the observation of obsolescence of materials are also essential. In many cases, materials are held in inventory for long periods and exposed to inappropriate storage conditions.

Table 15 – Items in Risk Management

Items	Key References
Consider a wide typology of risks	Grimsey and Lewis (2002), Zsidisin and Smith (2005)
Consider in the risk assessment not only tier-1 suppliers, but also relevant tier-2, tier-3, and suppliers in other tiers if applicable	New (2010), HMG (2013)
List and categorize supply chain risks	Gosling *et al.* (2013b), Simchi-Levi *et al.* (2014)
Cross-reference risks with sources of uncertainties	Gosling *et al.* (2013b)
Calculate the time to recover from disruptions (especially those related to unpredictable events)	Simchi-Levi *et al.* (2014)
Allocate inventory, capacity, and time buffers where applicable	Azambuja and O'Brien (2009)
Monitor the obsolescence of materials	Holweg and Pil (2001)

5.2.1.2 Flexibility Management

Flexibility Management is proposed as a practice to tackle problems and to improve the relationships at Interface C. Previous research in this field was evaluated and adapted in a set of items, which are depicted in Table 16.

Table 16 – Items in Flexibility Management

Items	Key References
Increase supply chain integration and responsiveness by sharing real-time information and investing in long-term partnerships	Lee (2004), Whitten *et al.* (2012)
Categorize suppliers and share risks according to uncertainty patterns	Whitten *et al.* (2012), Gosling *et al.* (2013a)
Design flexible products and facilitate production postponement	Lee (2004), Whitten *et al.* (2012), Gosling *et al.* (2013a)
Identify and categorize uncertainties	Whitten *et al.* (2012), Gosling *et al.* (2013a)
Identify new supply bases and markets constantly	Whitten *et al.* (2012)

Increased flexibility is a key issue in ETO supply chain structures. The level of responsiveness, the lead variable in this topic, can be improved by sharing real-time information and investing in long-term partnerships with suppliers. The suppliers must be categorized and cross-referenced with risks derived from uncertainty patterns. Products should be designed so that flexibility can be achieved in the product itself and in the production process. The identification and categorization of uncertainties is recommended, so that accurate contingency plans can be devised. Finally, the constant observation of markets in order to identify potential suppliers is suggested. These suppliers might be included in the contingency plans or incorporated in the supplier base.

5.2.2 Practices for Improving Construction Supply Chains

Construction supply chains require increased competitiveness. The following practices were investigated in the literature and they are initially recommended for supply chain improvement.

5.2.2.1 Performance Measurement and Benchmarking

Performance Measurement and Benchmarking is proposed as a practice to tackle problems and to improve the relationships at Interface C. Previous research in this field was evaluated and adapted in a set of items, which are depicted in Table 17.

Table 17 – Items in Performance Measurement and Benchmarking

Items	Key References
Implement qualitative and quantitative metrics	Beamon (1999)
Balance the number of metrics according to the competitive priorities	Hayes and Wheelwright (1979b)
Consider multiple competitive dimensions when implementing performance measurement	Melnyk *et al.* (2010), Estampe *et al.* (2013)
Consider the context in which metrics will be developed	Childerhouse *et al.* (2003)
Cascade performance measurement across different organization and supply chain levels	Garcia *et al.* (2012)
Enable benchmarking where possible	Garcia *et al.* (2012)

The concepts supporting performance measurement and benchmarking are interconnected. The implementation of both qualitative and quantitative metrics in performance measurement systems is recommended. The number of metrics should be balanced between the competitive priorities and additional competitive dimensions to be added. Metrics should also be implemented considering the specific context or industry. It is suggested that the metrics be cascaded across all internal and external (i.e. supply chain) levels. Finally, benchmarking should be used where possible to increase collaboration and capture lessons learned in a structured way.

5.2.2.2 Supplier Relationship Management

Supplier Relationship Management is proposed as a practice to tackle problems and to improve the relationships at Interface B. Previous research in this field was evaluated and adapted in a set of items, which are depicted in Table 18.

Table 18 – Items in Supplier Relationship Management

Items	Key References
Implement long-term partnerships with suppliers based on relevant criteria	Ellram and Cooper (1990)
Increase information sharing regarding planning activities	Ellram and Cooper (1993)
Implement strategies supporting early supplier involvement	Janda *et al.* (2002)

The establishment of long-term relationships with suppliers is recommended. The benefits of such practices, which in general contribute to direct and indirect cost reductions are reported in the literature. It is advised that the level of information sharing and transparency across the supply chain be increased. Finally, the implementation of early supplier involvement is recommended where possible. Such practice enables collaboration and contributes for reduced problems during the project's life cycle.

5.2.2.3 Improvement Planning

Improvement Planning is proposed as a practice to tackle problems and to improve the relationships at Interface A. Previous research in this field was evaluated and adapted in a set of items, which are depicted in Table 19.

Table 19 – Items in Improvement Planning

Items	Key References
Increase multi organizational commitment towards improvement and involvement with key suppliers	McGinnis and Vallopra (2001)
Reduce formality concerning supplier involvement	McGinnis and Vallopra (2001)
Implement improvement tools in partnership with suppliers	Corbett *et al.* (1999), Foggin *et al.* (2004), Drysdale (2013)
Increase benchmarking to capture best practices from suppliers	Luu *et al.* (2008)

The adoption of a plan sustaining improvement efforts is recommended. The plan should emphasize the importance of increased multi-organizational commitment towards improvement, and intense purchasing involvement with key suppliers. It is advised that the level of formality regarding decision-making concerning supplier involvement be reduced. The implementation of improvement tools in partnership with suppliers, so that successful results can be shared across the supply chain was found to be a positive practice. Finally, the implementation of structured benchmarking as a means for improvement is highly recommended, given its powerful contribution for capturing best practices across the supply chain.

5.3 Initial View of the Framework

The framework developed in this research for managing construction supply chains is supported by findings from three streams: literature review, exploratory interviews, and exploratory research in Company A. The literature review was organized so that, at the end of each sub-section, there is a summary and critique. The chapter of exploratory research was organized in a way that, at the end of each sub-section, the inputs for developing the framework are summarized. This information was cross-referenced in order to provide the underpinnings of the proposed framework.

The embedded features regarding the conceptualization of construction supply chains are discussed in order to link them to the above-mentioned streams:

a) **Two managerial levels** are considered in the conceptualization. The project level is composed of multiple and concurrent projects, and therefore it is reasonable to detach them from the enterprise level. Such division is motivated by the fact projects are one-of-a-kind and temporary. In this sense, there are short-term and mid-term considerations regarding projects that should be treated specifically. At the enterprise level, the considerations regarding supply chain management are not project specific, and they are focused on the long-term.

b) **Three interfaces** represent the connections between all key parties in a construction supply chain. Such interfaces provide a background for understanding the relationships between the parties and for locating eventual problems as they occur. By locating the problems at the interfaces, it is likely that the actions devised to tackle such problems are more efficient.

c) In order to connect the interfaces, **three types of flows** are proposed in the conceptualization: information, materials and services, and capital. In order to provide a better picture of reality, the flows were allocated at the interfaces according to their fit. Some of the flows are more frequent, and therefore more essential to particular interfaces.

d) The concepts regarding the **structural dimensions and business process links** from the GSCF Model are taken into consideration. The proposed conceptualization of construction supply chains is centred with the focal company, which is represented by the enterprise level. However, the original proposition of the GSCF Model is adapted so that the supplier level can be linked directly to different projects in the project level.

e) The model of the **logical factory** is reflected on the proposed conceptualization. In this context, the proposition has a viewpoint in which the supply chain should be managed as a production system, in which suppliers, projects, and the enterprise level have interconnected functions. The **production template**, comprised of three principles (design, operation and control, and improvement), is incorporated in the proposition along with the **flow** view of production. In this context, the flows connecting the interfaces form an essential underpinning of the conceptual view of construction supply chains proposed.

f) The **intrinsic characteristics of construction companies** are fully considered in the proposition. The conceptual view complies with the requirements of the project-based production system, multiple and concurrent projects, dispersed site locations, and uniqueness of schemes.

g) The **features of construction supply chains** are taken into consideration in the conceptual view proposed. The proposition complies with the needs of the project-based structure, network design, interfaces, supplier base, fragmentation, and demand forecast.

The proposed set of practices was developed from the literature review. The practices were initially allocated at specific interfaces, as an initial attempt to tackle supply chain problems as shown in Figure 42:

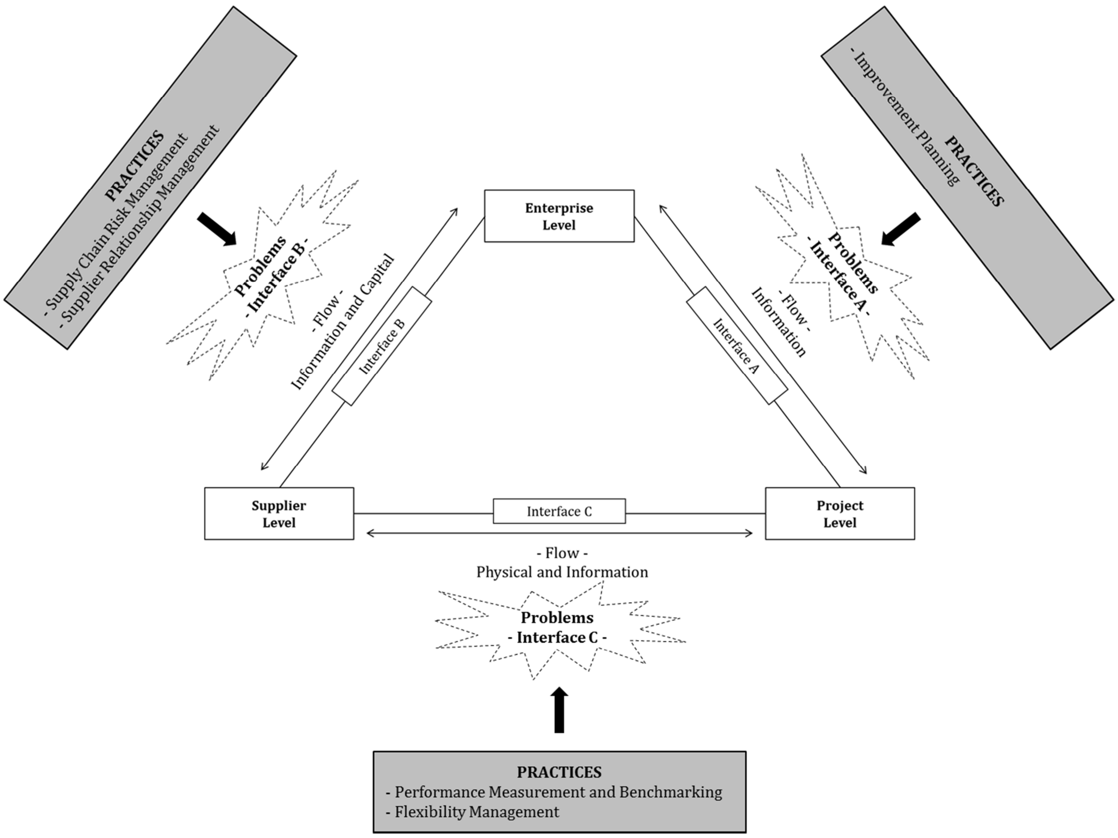


Figure 42 – Overview of the Framework (first version)

The conceptual view of construction supply chains is positioned at the centre, and the representation of problems is then situated at the interfaces. The specific sets of practices are connected to the relevant interfaces, in order to illustrate their contribution for solving problems and in supporting supply chain design and improvement in the long run.

6 REFINING THE FRAMEWORK

The refinement of the framework is presented in this chapter as shown in Figure 43. Three case studies were conducted in different companies, and a learning cycle was carried out after each case was completed. Next, a cross-case analysis was conducted to consolidate the inputs leading to the second version of the framework. In this sense, the first version was fully reviewed, refined, and assessed according to the research method proposed.

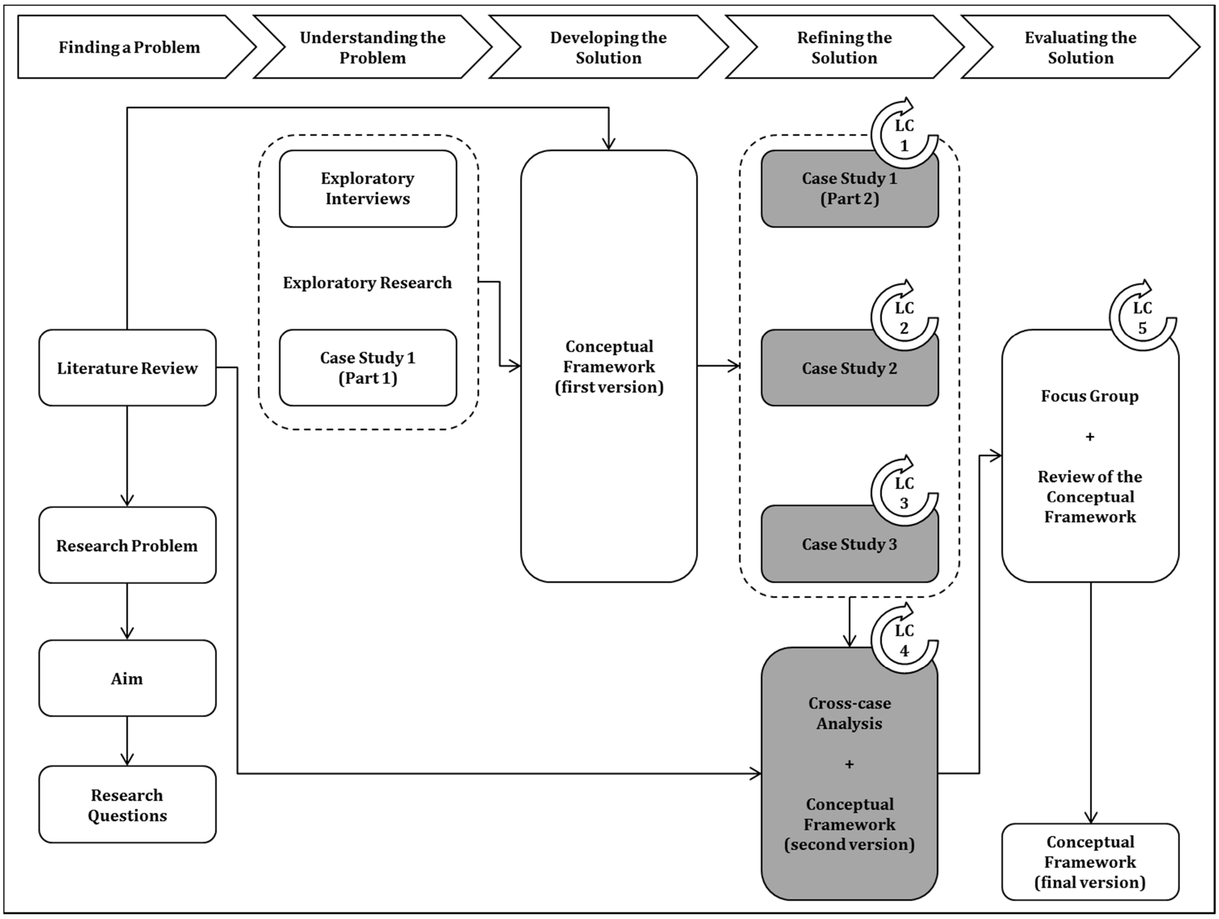


Figure 43 – Activities and developments in the 'Refining the Solution' stage

6.1 Case Study 1 (Part 2) – Report

Company A is a major construction company in Brazil. It is focused on infrastructure projects such as tunnelling, earthworks, and highways construction. Case Study 1 (Part 2) was carried out in Company A from November 2013 to December 2013. The study comprised different areas across the company, including procurement, quality, and cost control. Research was conducted by meetings with representatives of Company A, collection and analysis of documents, among others. The selection of participants to be interviewed was conducted by Company A based on the following criteria: experience, availability, time for completing the study, and levels of confidentiality of information. Meetings with the company's procurement, costs, and quality representatives are listed in Table 20.

Table 20 – List of meetings in Case Study 1 (Part 2)

Meetings	Position of the Participant	Level
1	Procurement Manager and Procurement Associate	Enterprise
2	Procurement Associate	Enterprise
3	Procurement Associate and Senior Costs Associate	Enterprise
4	Procurement Associate and Senior Quality Associate	Enterprise
5	Procurement Associate	Enterprise
6	Procurement Associate	Enterprise
7	Procurement Manager and Procurement Associate	Enterprise
8	Procurement Associate	Enterprise
9	Procurement Associate	Enterprise
10	Procurement Manager and Procurement Associate	Enterprise
11	Procurement Associate and Senior Quality Associate	Enterprise
12	Procurement Manager and Procurement Associate	Enterprise

Additionally, two workshops were carried out aiming at (i) discussing supply chain problems with the procurement department, and (ii) validating findings with the board of directors of Company A. The selection of practices to be assessed was based on the scope of activities, relevance of achievements, and availability of information to be provided. The activities of Case Study 1 (Part 2) were concentrated in assessing the following practices:

- Performance Measurement and Benchmarking;
- Supplier Relationship Management;

- Supply Chain Risk Management;
- Flexibility Management;
- Improvement Planning.

6.1.1 Practices Investigated

The following sections present the practices investigated. For each practice a detailed report of the findings and a feedback regarding points to be improved is given.

6.1.1.1 Performance Measurement and Benchmarking

Company A measures and reports the performance of its supply chain on a quarterly basis to the board of directors. Performance measures are listed below:

a) The metric named as **Rushed RFPs** measures the percentage of Request for Proposals (RFP) marked as urgent. This metric comprises all RFPs and it is measured month by month. Information available in Company A's database is compiled in spreadsheets by the procurement department. The objective of this measure is to assess at what level purchase orders are placed with suppliers on an urgent basis. Although there is significant control over the RFPs, data indicate that RFPs flagged as urgent represent 39% of the total. These data refer to the average percentage of Rushed RFPs in 2013. In addition, during interviews limited awareness regarding the impacts of rushed actions in procurement was observed, especially those related to increased costs, delivery delays, and poor quality. However, a set of actions in order to improve the performance of this metric is under development.

b) The difference of **Actual Costs vs Planned Costs** is measured on a project basis. Company A compiles information from all 26 projects in spreadsheets to assess the average price paid for materials. Project managers observe the planned costs, which were originally estimated by the Bid Manager in the commercial team before the project's start, and compare them with actual costs executed in projects. It was observed that, although Company A is able to calculate Actual Costs vs Planned Costs on a monthly basis, the procurement department only consolidates and calculates the metric at the time of submitting the report to the board of directors. Interviewees in the procurement department mentioned that the days prior to the deadline of submission are 'stressful', mostly because people at the project level usually make last-minute inputs to the spreadsheets. Differences are evaluated in relation to an established target for cost reduction, which is 2.5%. In direct terms, this target specifies that actual costs should be at least 2.5% less than the planned costs. Consolidated data from all running projects in 2013 and 2014 are represented in Table 21. In 2013, actual costs were reduced by 4.51% when compared to the planned costs. Thus, the target has been surpassed. However, data obtained from Company A in 2014 demonstrated that from January 2014 to March 2014 costs did not follow the same pattern, as the reduction was only 2.94%.

Table 21 – Planned Costs vs Actual Costs

	Δ Actual Costs vs Planned Costs	**Target**
January 2013 to December 2013 (%)	-4.51%	-2.5%
January 2014 to March2014 (%)	-2.94%	-3.0%

c) **Processing Time** comprises the time between when Requests for Proposal (RFP) are placed and when materials are actually delivered on site. The objective is to measure the lead-time of supply. Interviewees reported a concern regarding the length of Processing Time, which in the year 2013 was calculated as 19.82 days on average. Although data is collected on a monthly basis for calculating this metric, there is no periodic analysis of the information provided. A detailed examination only takes place when the report is submitted to the board of directors every quarter. In addition, the major concern demonstrated by interviewees in Company A was with the number itself, which is considered too high. However, concerns regarding variability in processing time, and therefore potential wastes, were not reported during interviews.

There is a lack of organization in the procurement department to discuss results of performance measurement. During interviews, performance measurement was reported as ‘top-down’, and therefore the major concern is to prepare information to be submitted to the board of directors. In the board, metrics from all areas of Company A are then analysed and corrective actions are directed.

The use of performance measurement for supporting decision-making in Company A is limited. There is a low level of awareness regarding the performance of the supply chain and its impacts on Company A. In addition, feedback to suppliers regarding their own performance is limited to an annual letter sent to critical suppliers. Criteria for defining critical suppliers were not disclosed, nor were the contents of the letters.

There are limited interactions between the procurement department and other areas in terms of performance measurement and benchmarking. For example, although the difference of Actual Costs vs Planned Costs is measured, there are no joint efforts with the commercial area to improve the performance of this indicator. In many cases, it was reported by interviewees that planned costs are not accurate.

In order to summarize and evaluate Performance Measurement and Benchmarking in Case Study 1 (Part 2), the following points are presented:

- **Positive aspects:** Company A measures financial and operational dimensions of its supply chain performance. There is a concern regarding the frequency of measurement, given metrics need to be reported to the board of directors quarterly. The measurement of Processing Time should be highlighted as a relevant indicator, once the metric provides an overall idea of the performance of the process. The findings of Case Study 1 (Part 1) produced significant changes in Company A after they were presented to the board of directors. Currently, there is an action plan for reviewing general guidelines regarding supply chain performance measurement and benchmarking;
- **Recommendations for improvement:** In order to streamline the process for data gathering, the adoption of templates for data collection is recommended. By doing so, people at the project level will be to able input information in a standardized fashion, which contributes to reducing waste at this stage (i.e. rework in the task of entering data). In addition, it is recommended that the template be available (i.e. web-based) to the procurement team, especially to follow-up whether information has been inserted on time. There is a lack of balance and breadth of current performance measures adopted by Company A. The adoption of metrics related to multiple competitive dimensions, including quality, flexibility, among others, is recommended. Performance measurement should be used in Company A for purposes different from control. It is recommended that metrics support decision-making and enable benchmarking. First, the performance of the supply chain should be taken into account for

developing action plans. Although Company A has a high level of Rushed RFPs (57%), there are no action plans implemented to integrate efforts from different areas and improve such a result. Second, Company A should use information in its database to compare the performance of suppliers and projects on an individual basis. By using performance measures, it would be possible to assess where increased performance is achieved, capture lessons to be learned, and set new targets to be achieved. Finally, Company A should assess the level of variability in its supply chain performance, especially in metrics concerning operational aspects such as Processing Time.

6.1.1.2 Supplier Relationship Management

Company A develops relationships with its supply chain following an informal structure. As suppliers are not categorized, there are limitations for determining what, how, and when suppliers should be approached.

The adoption of structured strategic alliances or long-term partnerships between Company A and its suppliers is not observed. Although some suppliers have been working with the company over the last 20 years, there is no strategic view regarding this topic. In addition, trust was pointed out as limited between Company A and its suppliers. The majority of the decisions are price-driven, which leads to a large and fragmented supplier base.

It was reported that only a group of specific suppliers, in which the level of spend is high, has increased contact with Company A. The relationship is conducted by periodic meetings, which are typically concentrated on the discussion of commercial aspects of contracts. These companies supply high-consumption materials such as grit, concrete, sand, asphalt, explosives, drill bits, health and safety equipment, and spare parts and components to be applied in equipment and vehicle maintenance.

In general, the relationship with suppliers is mainly carried out in transactional procedures: phone conferences, meetings, Request for Proposals (RFP), Purchase Orders (PO), invoices, contracts, and e-mails. In the case of Purchase Orders, the clarity of the information provided should be positively emphasized, as listed below:

- Identification and registration of POs in a central database;

- Relevant information for preparing invoices;
- Relevant information for delivery;
- Specification, quantities, and reference numbers (where applicable) of materials and services;
- Prices and commercial conditions;
- Specific instructions provided by the team at the project level (i.e. guidelines for accessing the site, directions for unloading and loading materials and equipment).

In Company A, there is limited discussion regarding design and improvement aspects. For example, there are no regular committees or forums for discussing supply chain problems such as delivery delays, issues in quality, and health and safety aspects, among others. In addition, little interaction with suppliers was observed such as site visits, regular business-to-business meetings, and feedback of evaluations, among others.

In addition, there is a significant share of operational activities carried out by buyers in Company A that do not add value. This share is related to the task of registering prices after RFPs are supplied by suppliers. As the process is based on the exchange of e-mails, all suppliers reply formally to the RFPs in individual messages directed to particular buyers. Internal policies in Company A mandate that three prices from different suppliers are quoted for each RFP. In a hypothetical situation in which a single RFP has 5 items, 15 prices would require manual input in the system. Prices are registered for auditing purposes and to enable further comparison before a Purchase Order is placed to a specific supplier. As previously highlighted, 4,000 RFPs are generated every month, and consequently buyers spend a significant amount of time registering prices in the system.

As part of the development of this research, Company A agreed to conduct a pilot workshop with suppliers. Prior to the workshop, 10 suppliers were formally invited to attend the session, which took place in Company A headquarters and took 2 hours. The objective of this activity was centred on discussing the following questions:

- What are the challenges faced by suppliers when sourcing materials and services to Company A?

- How can the existing flows of information, materials and services, and capital be improved?

A briefing regarding the background of this research was presented. Representatives of suppliers were then divided into two small groups of five participants. Representatives of Company A conducted the discussion within the groups, and summarized the outcomes in bullet points on flip charts. A discussion with all participants was then facilitated by the Procurement Manager of Company A. Issues pointed out by suppliers are those related to poor integration with Company A, lack of attention from the procurement area, pressures regarding contracts and prices, difficulties in accessing information, among others.

Afterwards, a meeting with representatives from Company A was conducted in order to evaluate the positive aspects of the workshop. It was reported that a simple activity, such as a two-hour workshop with suppliers, could provide valuable insights regarding supply chain improvement. In addition, representatives in the procurement department of Company A emphasized the 'positive atmosphere' in which the topics were discussed. An action plan was devised in order to tackle the specific issues pointed out by suppliers during the exercise.

In order to summarize and evaluate Supplier Relationship Management in Case Study 1 (Part 2), the following points are discussed:

- **Positive aspects:** there are established transactional protocols between Company A and its supply chain. A high level of compliance with the protocols is observed, especially in the procurement department. Suppliers with whom there is a high level of spend receive increased attention from Company A. The composition of the format and contents of Purchase Orders is very clear, which contributes to reducing the level of rework in the procurement process;
- **Recommendations for improvement:** the categorization of suppliers and the development of specific relationship strategies are recommended. An increased day-to-day contact with the supply chain, by promoting workshops, supplier days, and site visits is also suggested. Issues regarding supply chain improvement should be shared with suppliers, so that committees can be organized in particular topics (i.e. quality, sustainability). Ultimately, these forums can be used

for sharing lessons learned between suppliers and to foster a collaborative environment. Concerning transactional activities, the adoption of a web-based portal to interact with its supply chain is recommended to Company A. In the current situation, buyers are exposed to a significant share of non-value added activities. In order to increase transparency, security, and reduce the share of non-value added activities in Company A, it is suggested that suppliers input their prices for the respective RFPs.

6.1.1.3 Supply Chain Risk Management

Company A has a strict protocol for assessing supply chain risks when selecting suppliers. In addition, interviewees reported the existence of frequent audits to check whether all procedures are followed by Company A employees.

The risk assessment protocol contains different stages, which are described as follows:

a) Suppliers must complete the 'Self-assessment Questionnaire', which contains general contact and legal information for future reference. Suppliers indicate whether they have an ISO9001 certification. Moreover, they should provide evidence regarding procedures for selecting and evaluating their own suppliers. Finally, suppliers must provide information regarding current and past customers, so that they can be consulted for referencing purposes.

b) Internally, Company A determines whether a site visit is required after the self-assessment is handed-in. The objective of the site visit is to assess facilities, equipment, capacity, conditions of storage areas, among others. Decisions regarding which suppliers should be visited is made by the procurement department, after considering the operational risks concerning the materials and services to be sourced. Environmental and Health and Safety (EHS) aspects are verified only in suppliers of services.

c) Legal aspects are verified by the legal and taxes department, in which government and private databases are consulted to check financial issues of suppliers. Any inconsistency found in the legal or financial aspects of the supplier is mandatory to cancel its registration with Company A.

d) Based on the evidence provided by the supplier, operational aspects verified in the site visit, and reports regarding legal and financial issues, a final recommendation is made. The final recommendation should be signed off by the Procurement Manager before a formal registration is made in Company A systems. After registration, a unique reference number is attributed to each supplier.

Company A has a list of 480 materials considered critical. These materials are classified in this way because any non-conformance found in them can harm the quality of works on site, cause disruption in the activities, and ultimately affect EHS aspects. Potential suppliers for any of the 480 items listed as critical should comply with ISO9001 requirements, and therefore additional verifications might be required at the discretion of Company A. It is worth mentioning that a list of critical services was not found.

Apart from the protocol for assessing supply chain risks for selection purposes, no routine for assessing suppliers systematically was found. In addition, the internal procedures presented by Company A do not comprise long-term supply chain assessments. Interviews demonstrated a clear notion that risk assessments are very important, but in the opinion of interviewees, they demand too much effort.

In order to summarize and evaluate Supply Chain Risk Management in Case Study 1 (Part 2), the following points are emphasized:

- **Positive aspects:** the risk assessment protocol adopted by Company A is comprehensive, given it comprises both financial and operational issues. There is a high level of awareness regarding the procedures to be followed and the approvals required after assessments are completed. The existence of systematic audits is highlighted, given its relevance in assuring the processes. In addition, the adoption of site visits is very positive, once real conditions can be evaluated together with the suppliers and their customers (where applicable). The cross-functional process adopted by Company A in managing risks should be positively emphasized, given that all internal departments are directly or indirectly involved (i.e. procurement, legal, taxes);
- **Recommendations for improvement:** the adoption of a systematic approach to manage risks in Company A is suggested. Currently, risks are assessed when the supplier is registered for the first time in the company's database. However, risks tend to increase or change over time, which required the adoption of different

approaches towards risks. On the one hand, it is suggested that Company A monitors constantly the financial risks of high spend suppliers. On the other hand, it is also recommended that the Company carry out frequent site visits to the most relevant suppliers, which can be included in the calendar of procurement representatives. By adopting such pro-active behaviour, Company A will be able to reduce or mitigate potential risks in its supply chain. It is finally suggested that Company A review the list of critical materials on a periodic basis, and include critical services as well. These lists should be constantly updated and cross-referenced with the systematic risk assessment of suppliers proposed.

6.1.1.4 Flexibility Management

A high level of tacit knowledge regarding flexibility, and its direct relation with uncertainty is observed in Company A. Interviewees reported different approaches they use on a daily basis to tackle the impacts of uncertainty in managing production on site. These approaches include inventory buffers and relocation of capacity and outsourcing, among others:

a) **Inventory buffers** are allocated to all project sites. First, as Company A has a large fleet of equipment, a significant share of inventory comprise specialty parts to be replaced in heavy excavators, off-road trucks, and drilling jumbos. It was found that Project Managers have different inventory policies for storing spare-parts on site. Some Project Managers prefer reduced inventories, so that they order parts from the suppliers when necessary. These Project Managers rely on demand patterns for spare parts, which are provided by the maintenance department. Other Project Managers prefer increased inventory levels, so that they do not have to wait for the delivery of spare parts. The first group of Project Managers contributes to reducing inventory levels in Company A. However, they have an increased risk of disruptions in their operations, especially those located far away from the suppliers. The second group of Project Managers do not contribute to reducing inventory levels, but they are not likely to have disruptions in their construction sites due to out-of-stock spare parts. Both strategies produce significant implications in the supply chain of Company A. Second, there is also a significant share of inventory of materials to be consumed on site such as precast concrete tubes, aggregates for asphalt sub-bases, precast curbs, among others. These materials are delivered on site by suppliers, but the level of synchronization with production is low. As the majority of projects developed by Company A are located in remote sites, Project Managers tend to stay on the safe side, and therefore accumulate high quantities of materials to be consumed later in order to avoid disruptions. Historic data in Company A indicate poor delivery reliability of its supply chain due to two central reasons: difficulties in logistics and limited communication between project sites and suppliers. There is no action plan to streamline and coordinate inventory policies in Company A.

b) **Relocation of capacity and outsourcing** are performed by Company A. The Production Director overlooks all concurrent project sites and maintains daily contact with his team of Project Managers. These contacts occur in an ad hoc basis, mostly by telephone conferences and site visits. Operational problems and specific demands are reported by Project Managers to the Production Director, who centralizes all decisions. Interviewees reported that the relocation of equipment, labour, and inventories between the different project sites is a common practice in Company A. In this complex scenario, there are two central roles performed by the Procurement Manager and by the Maintenance Manager. Both managers provide up to date information regarding materials and services to be supplied and equipment under maintenance. If additional capacity is required, and such requirement exceeds the internal possibilities of Company A, outsourcing is then authorized by the Production Director. Typical activities outsourced include renting equipment and mobilizing specialized crews to execute services. Generally, decisions regarding outsourcing are made at the last minute, and therefore they demand a great effort from the procurement team. As production planning is centralized by the Production Director, the planning process is sometimes carried out on the 'spur-of-the-moment', as reported by some interviewees.

Regarding inventory buffers, the major problems reported by interviewees is the obsolescence of materials. In many cases, materials are not fully consumed during the project's life cycle, which generates remaining inventories. In general, these materials are catalogued, transported, and finally stored in Company A headquarters. In a visit to this storage area, a large amount of obsolete materials was found. An action plan directed to improve the accuracy of demand of materials was not found in Company A. In addition, interviewees reported that projects do not pay for exceeding materials, which means that the cost of such materials is debited from the overall budget of Company A.

Regarding relocation of capacity and outsourcing, the major difficulties reported in interviews are those related to last-minute requirements. As the planning process is limited in integration, and therefore it is performed in an unstructured fashion, the indications of relocation of capacity are mostly rushed. There are significant impacts in cost, quality, and time derived from such recurrent conduct.

In order to summarize and evaluate Flexibility Management in Case Study 1 (Part 2), the following points are discussed:

- **Positive aspects:** the practices adopted by Company A, regarding Flexibility Management, are consistent with the problems encountered. As the level of variability is high, Company A adopts inventory buffers as a strategy to minimize disruptions. In addition, relocation of capacity and outsourcing are deployed when necessary based on centralized decision-making. Both approaches contribute to mitigating supply chain disruptions;
- **Recommendations for improvement:** a structured map of uncertainties was not found in Company A. The adoption of a pro-active method to identify the sources of uncertainty and categorize them systematically is recommended. From an external perspective, one can view all the action as concentrated in firefighting the effects of uncertainty in the processes. One example to illustrate the discussion is the 'rushed environment' reported by interviewees when relocation of capacity is required. In addition, the lack of consistency in procedures is exemplified by a variety of approaches regarding inventory management adopted across projects' sites. It is recommended that Company A map its sources of uncertainty, and establish a cause-and-effect relationship with their impacts. In addition, it is recommended that such uncertainties be also categorized, in order to direct actions properly. It is also suggested that Company A take a next step in terms of planning, as currently planning activities are centralized but not integrated. In this sense, Company A should gather information from project sites systematically and cross-reference them before decisions are made.

6.1.1.5 Improvement Planning

Efforts regarding supply chain improvement are carried out by Company A. There is good integration between internal departments for discussing supply chain problems, and possible solutions for them. However, as the relationship with its supply chain is mostly transactional, there is a lack of actual implementation of such plans with suppliers.

There is a positive integration between the procurement, cost control, and quality departments. Interviewees pointed out that such integration is recent, and actually it was mostly motivated by the diagnostics provided by this research in Case Study 1 (Part 1). On this occasion, it was suggested that improvement initiatives should be developed by Company A in partnership with its supply chain.

The quality department has a good level of expertise to support the procurement department in identifying supply chain problems. In addition, representatives from the cost control section demonstrated significant knowledge regarding the production process. Interviewees pointed out that the combination of efforts from these two areas with procurement might produce significant impacts for developing action plans regarding supply chain improvement.

Company A reported a set of steps regarding improvement planning, which are summarized as follows:

- Identification of supply chain problems;
- Categorization of supply chain gaps according to the problems faced by Company A in project delivery (i.e. cost overruns, poor quality);
- Devise actions to be implemented by the procurement department.

The quality and cost control department support the identification and categorization of gaps. However, as these departments do not have direct contact with suppliers, they do not participate in the implementation of devised actions. A number of action plans were found during data collection. Nevertheless, the majority of these plans were developed for the context of particular projects, and therefore they do not comprise an overall view of Company A's supply chain. In addition, it was found the actions developed have their focus on immediate solutions, which has implications to limited long-term improvement.

The registration of quality problems on a daily basis was evaluated in Company A. On construction sites, there are procedures indicating that all non-conformances in materials or services provided should be formally registered. Company A provided evidence demonstrating that operational personnel were trained in such procedures accordingly. However, the number of non-conformances registered is consistently low across all projects in Company A. When questioned in interviews, it was reported that problems happen frequently, but the focus is on solving them as quickly as possible, and therefore registration of problems is not a priority.

On the side of cost control, there is a set of procedures indicating how costs should be controlled at the project level. The procedures indicate planned costs for each work package in a particular project should be evaluated on a weekly basis. Deviations of planned costs caused by the supply chain should be justified, and this includes cost deviations produced by waste of materials and rework. Again, the level of deviations registered is consistently low across all projects in Company A.

Nevertheless, the manner in which Company A interacts with suppliers is a problem for implementing improvement plans. As the relationships between Company A and its suppliers are mostly transactional and ad hoc, suppliers do not often adhere to improvement propositions.

In order to summarize and evaluate Improvement Planning in Case Study 1 (Part 2), the following points are discussed:

- **Positive aspects:** the integration of multiple departments (i.e. procurement, quality, and cost control) to deploy supply chain improvement in Company A is clear. This combination is needed to ensure that robust and comprehensive plans are developed to tackle supply chain issues. The steps carried out by Company A to plan improvements appear to follow a logical sequence. The procedures used in the registration of non-conformances and cost deviations appear as a positive aspect to support improvement planning, given they provide information for future reference. In addition, the training process fostered by Company A for its employees is well developed;
- **Recommendations for improvement:** the reduction and categorization of its supply chain is recommended to Company A. By streamlining its relationships

with suppliers, the company will be able to implement the action plans deployed. Moreover, improvement planning should not be carried out on a project basis; it should be managed on a wider and long-term perspective at the enterprise level. Finally, the registration of non-conformances produced by the supply chain in Company A is recommended. Registration of problems is the most effective way to capture precise information for devising effective improvement plans.

6.1.2 Learning Cycle of Case Study 1 (Part 2)

The case study in Company A assessed a set of practices for designing and improving construction supply chains. In addition, aspects concerning the conceptual framework proposed in this research were indirectly reviewed.

First, the form in which Company A manages its supply chain should be highlighted. Projects present unique characteristics in terms of their scope, duration, location, and materials to be used. Projects are multiple, simultaneous, and geographically dispersed across Brazil. The majority of projects are concentrated in the highways and mining sectors. At the project level, there is an independent structure managed by a project manager. Regarding supply chain management, both activities at the project and enterprise level should be coordinated. Company A has a wide supplier base, containing more than 4,200 active suppliers. There are interfaces between the corporate level, projects, and suppliers. Such interfaces are interconnected by flows, especially those concerning information, materials, and capital. Company A does not have a clear understanding of the root causes of its supply chain problems. However, there is tacit knowledge regarding the effects of such problems, and therefore managers in Company A implemented selected 'remedies'.

Second, a set of five practices was investigated in Company A. Performance Measurement and Benchmarking are key elements sustaining supply chain improvement over time. Company A observes a determined frequency for measuring supply chain performance. However, benchmarking is limited across suppliers, and therefore practices are not properly exchanged. Supplier Relationship Management follows strict protocols, which were found as consistent in Company A. The categorization of suppliers is suggested to support the strategies devised by Company A in terms of relationship management. Supply Chain Risk Management encompasses an assessment protocol containing both financial and operational issues. The adoption of a pro-active behaviour by Company A to manage supply risks is advised. Flexibility Management is carried out by Company A by adopting inventory buffers as a strategy to minimize disruptions. In addition, the adoption of pro-active methods to identify the sources of uncertainty and categorize them systematically is recommended. Improvement Planning in Company A is supported by high cross-departmental interactions (i.e. procurement, quality, and cost control). In addition, the adoption of a long-term view to manage supply chains from the perspective of the enterprise is suggested.

6.2 Case Study 2 – Report

Company B is a major construction company in the UK market. Company B develops projects mainly for the government, which typically comprise highways, water, and energy, among others. The company outsources the majority of its works, which adds up to approximately 80% of spend concentrated in subcontractors. Case Study 2 was carried out in Company B from March 2014 to August 2014. The study comprised different areas across the company, including procurement, commercial, corporate supply chain management, and project management.

Case Study 2 comprised interviews, participation and observation of meetings, and collection of documents. Representatives from one construction site, and from the procurement and supply chain departments within Company B were approached. The selection of participants to be interviewed was conducted by Company B based on the following criteria: experience, availability, time for completing the study, and levels of confidentiality of information. Table 22 lists the interviews carried out in case Study 2.

Representatives from Company B were mainly in senior positions. Such representatives were previously approached in a formal way, so that proper arrangements for interviews could be done in advance. In addition, documents were collected throughout the research process. Such documents were archived physically and digitally in order to support findings of this research.

Table 22 – List of interviews and meetings in Case Study 2

Item	Position of the Participant	Activity
1	Proj. Manager, Snr. Quantity Surveyor, Quantity Surveyor, Commerc. Manager	Interview
2	Commercial Manager, Snr. Quantity Surveyor	Interview
3	Snr. Quantity Surveyor	Interview
4	Supply Chain Manager – Subcontractors	Interview
5	Supply Chain Manager	Interview
6	Commercial Director	Interview
7	Supply Chain Manager – Materials	Interview
8	Data Validation	Meeting

The selection of practices to be assessed was based on the scope of activities, relevance of achievements, and availability of information to be provided. The activities of Case Study 2 were concentrated on assessing the following practices:

- Long-term Supply Chain Governance;
- Supplier Base Management;
- Category Management;
- Early Supplier Involvement;
- Supplier Development;
- Performance Measurement and Benchmarking;
- Procurement Scheduling;
- Supply Chain Risk Management;
- Fragmentation Management.

6.2.1 Practices Investigated

The following sections present the practices investigated. For each practice a detailed report of the findings and a feedback regarding points to be improved is given.

6.2.1.1 Long-term Supply Chain Governance

The governance role performed by Company B is embedded in its business culture. At the very beginning of an interview, a representative of Company B stated:

"we do not have a master-servant relationship".

Awareness regarding supply chain governance in Company B is considerably high as well. All interviewees demonstrated a good level of understanding regarding their internal roles in the business as well as the overall role of Company B in its supply chain. Next, diverse topics related to supply chain governance and investigated in Company B are presented.

The recent shift in the mind-set of Company B at the business level is commented below:

> *"we are not a construction company, we are a service provider… and really with that, a shift came from… we are not just looking for pure construction projects".*

By adopting such a strategic position, Company B recognizes implications in its supply chain as stated below:

> *"… and this has broadened our delivery… the self-delivery aspect has really gone… I suppose we are looking to the programme management".*

80% of the spend of Company B is concentrated in subcontractors, which indicates increased levels of outsourcing. Interviewees pointed out that the above-mentioned changes started in 2011 and they created an increased level of engagement between Company B and its customers. Subsequent impacts are listed as follows.

First, Company B has a long-term view regarding supply chain management. In this sense, there are concerns about long-term, reliable, cost-efficient relationships with suppliers. One example captured is related to a supplier in the earthworks sector that used to be a SME 20 years ago, and is now a major player in the UK market. Company B believes that its supply chain is crucial for delivering the business plan each year given its high level of outsourcing - *"the majority of our spend is mainly for subcontractors… we don't do a lot self-delivery"*. In this sense, there is a concern about the level of financial co-dependence of suppliers. Co-dependence is constantly monitored, and specific action plans are devised for each supplier where applicable. During one of the interviews, a representative of Company B answered, *"I don't think this is a healthy place to be"***,** when asked about high levels of co-dependence still found in some suppliers.

Company B also has a structured supplier base, which is managed according to the level of relationship with suppliers. Those companies named as 'strategic' and 'preferred' have a strong level of business-to-business integration. Supplier base management will be detailed further. In this context, the long-term view adopted by Company B might be summarized as follows:

> *"if you want to have transactional procurement, do not bother with supply chain management at a group level, because you just get on with it… you can make those local decisions".*

Second, Company B has a clear understanding that both corporate and project levels should co-exist as aforementioned. According to interviewees, the strategic level of supply chain management *"is not a one-day job"* and therefore it requires specific personnel to deal with the challenges at this level. In this sense, the company has separate operational procurement and supply chain management activities. Operational procurement is subdivided into two levels, central procurement and project level. Central procurement is responsible for purchasing high spend materials and services, typically those over £5,000. In addition, central procurement is responsible for capturing and aggregating information from different project sites by interacting with the project level systematically. At the project level, the procurement team is responsible for compiling information from designs, generating quantity bills, and purchasing materials and services. Supply chain management activities are not concerned with particular projects, as they are mostly concentrated in shaping the supply chain for future challenges.

Third, Company B matched its business, projects, and supply chain structures. By doing so, Company B reduced significant non-value added activities and achieved better performance after the adoption of concepts from other industries, especially those from lean manufacturing. It is the opinion of the interviewees, however, that there is a long way to go:

> *"construction is trying to learn from all those industries… and I think we are still on that journey… and we are still nowhere near… of having that full understanding and lessons learned from manufacturing"*.

In addition, by matching its business, projects, and supply chain structure Company B increased its level of integration with suppliers. Due to high integration, the level of responsiveness to supply chain and market variations (i.e. changes in the scope of a particular project, price fluctuations in materials, disruptions and availability of workforce) becomes a critical issue to be addressed. Flexibility and responsiveness are used as synonyms by interviewees in Company B, and such attributes are highly valued as stated below:

> *"sometimes things change… and that is fine… you need to be flexible… it is not one size fits all… you have the different types of projects such as small, large, unique, bespoke… you know… if you can't be flexible, go home".*

Fourth, Company B acknowledges its own variety of projects. Given the company develops projects in different areas (i.e. highways, water, nuclear), it is natural that those projects differ in terms of scope, technical requirements, and location, among others. Nevertheless, it is also natural that those projects vary in terms of size, which produces significant implications in time, cost, and quality. Concerns regarding such diversity of projects are externalized as stated below:

> *"I think the most complex situation is when you have a very unique, very bespoke project… because the likelihood of having a supply chain that is already established and you have a relationship with… that maybe is not existent".*

Thus, a project might present unique supply chain requirements. Such requirements produce significant implications in the way materials and services are procured. In addition, Company B uses small projects as a training ground for its teams. In such projects, teams work closer to each other and it is possible to develop and implement one-on-one coaching activities. Typically, project managers at the beginning of their careers are allocated to projects presenting low levels of complexity in Company B.

Fifth, Company B tries to incorporate customers' requirements. In order to illustrate this topic, one of the interviewees highlighted:

> *"we need to go where our clients go… you know… at the end of the day I think our clients are more demanding… they are a little more switched on from what they were 15 years ago… right… they actually understand supply chain management… they know what they want to see".*

Company B is focused in the public sector. In this sense, the company has to integrate and coordinate its efforts with different organizations across multiple governmental sectors. Interviewees reported that numerous initiatives of the UK government have been implemented towards supply chain improvements, pushing development towards both tier-1 and tier-2 suppliers, comprising a wide range of SMEs. Company B reported the existence of structured projects and training schemes supporting the development of its suppliers. Even though the governmental organizations value supply chain development, the majority of their commercial decisions are still price driven. It is the opinion of the interviewees that clients have not realized in full the effort Company B has put in its supplier development initiatives. It is also clear for Company B that price-driven decisions contribute to reduced visibility in the pipeline of future projects.

Finally, governance aspects and their bearings on operations should be discussed. It was found that Company B interacts with suppliers via 'Request for Information' (RFI) and 'Request for Proposal' (RFP). Each item or work package requires quotes from 3 suppliers in the market, who have up to 21 days to reply with a quotation. In order to simplify activities and increase control, Company B reduced the number of suppliers participating in the tendering process by consolidating materials and services in larger packages to be quoted. It is worth mentioning that RFIs and RFPs are exchanged via e-mail, and a quantity surveyor keeps track of all them on a spreadsheet. There are approval levels in Company B, so that POs are approved by senior executives according to the level of spend. Approvals routes vary in terms of spend, nature of materials or services, and type of project. In the case that an urgent order is placed to a supplier, a verbal negotiation with suppliers is allowed in order to expedite the process. Urgent orders represent less than 5% of the total of orders at the project level, and they are typically related to items accounting for low spend. Purchase orders are sent out to suppliers via e-mail, although a hard copy is also forwarded.

In order to summarize and evaluate Long-term Supply Chain Governance in Case Study 2, the following points are presented:

- **Positive aspects:** long-term supply chain governance is established in Company B business culture. The long-term view adopted by Company B towards the task of managing its supply chain is correct. Concerns regarding the reduction of financial co-dependence of suppliers should be mentioned as a positive finding. Another positive aspect to be mentioned is the way Company B matched its business, projects, and supply chain. Such alignment enabled the interaction between both corporate and project levels, upholding the clear boundaries between these levels. By learning from different industries and production philosophies, especially lean manufacturing, Company B started to capture and deliver customers' requirements quickly. In addition, it should be underlined how Company B deals with projects' variety in a positive way, by using small projects as a training ground for its staff;

- **Recommendations for improvement:** there is limited integration between the commercial side of the business and procurement. Such lack of integration was reported by interviewees, which classified the interactions between commercial and supply chain management as ad hoc. Company B misses an opportunity to access relevant information regarding future projects from the commercial area and used it in supply chain planning. In addition, it would be possible to use the commercial representatives as a means to propagate to clients all efforts employed in supply chain improvement. Moreover, there is limited development in information technology in Company B for managing its supply chain. During the research process, it was possible to verify that integration with suppliers is not electronically automated. Such lack of integration produces significant impacts because purchase orders are not transmitted automatically and information regarding inventories is not available electronically.

6.2.1.2 Supplier Base Management

It is the opinion of interviewees in Company B that supplier base management is essential, otherwise ad-hoc supply chain relationships would be predominant, as highlighted below:

> *"when you have thousands of suppliers in a database, and there is no structure to it… it is just a database… and there is no knowledge or intelligence around them"*.

Company B adopts a four-level structure for managing its supply chain. The adoption of such a structure is intended to organize suppliers as follows:

a) **First level** comprises strategic partners and they add up to 50 suppliers. Suppliers at this level have long-term relationships with Company B and obtain high levels of spend, which are primarily conducted at the business level. In this sense, Company B and its strategic partners have increased alignment due to intense collaboration (i.e. business-to-business meetings, 360° evaluations).

Decisions at first level are not price-driven, once strategic partners have specific characteristics and service levels that comply with Company B requirements systematically. Early involvement with suppliers is fostered at this level, especially as an enabler of cost reduction and projects' improvement.

b) **Second level** includes preferred suppliers, which numbers 250 companies in total. Suppliers at this level have mid to long-term relationships with Company B and take mid to high levels of spend, managed both at business and project levels. High performers at this level are under consideration for future opportunities at the first level, which depends on market conditions. Decisions at second level are not price driven and there is a good level of early involvement with suppliers. The level of alignment with preferred suppliers is considerably high due to collaborative business-to-business meetings with Company B.

c) **Third level** involves around 900 verified suppliers. Suppliers at this level have short to mid-term relationships with Company B and account for reduced levels of spend. Usually, verified suppliers are managed at the project level and source specific materials or services. When a verified supplier has an outstanding performance, that company might be nominated as an alternative for replacing a supplier at the second level. Decisions at the third level are partially price driven and sometimes suppliers are used on a temporary basis. The level of alignment with verified suppliers is particularly low, given that levels of relationship with verified suppliers varies significantly in intensity.

d) **Fourth level** involves a large number (>1,000) of unverified suppliers. Suppliers at this level might be consulted for a particular project, considering specific needs. Such needs might be in terms of scope, technical requirements, and available capacity, among others. Suppliers at this fourth level are managed by the project level and decision making is completely price driven. Typically, unverified suppliers are geographically located close to the project site, which implies a temporary relationship with Company B. The level of alignment between Company B and unverified suppliers is considerably low.

Table 23 – Supplier base in Company B

Supplier Base Level	Number of Suppliers	Length of Relationships	Level of Spend	Degree of Collaboration	Decision-making
First	50	Long-term	High	Early Supplier Involvement, Business-to-Business Meetings, 360° Evaluations	Multi-criteria, Corporate level
Second	250	Mid to Long-term	Mid to High	Early Supplier Involvement, Business to Business Meetings	Multi-criteria, Corporate and project levels
Third	900	Short to Mid-term	Low to Mid	Mostly transactional, Performance Assessment	Price-driven, Project level
Fourth	>1,000	Short-term	Low	Ad-hoc, Performance Assessment	Price-driven, Project level

Table 23 summarizes the characteristics of the supplier base in Company B. The implementation of supplier base management in Company B was motivated by the idea of working with fewer and closer suppliers. In order to accomplish such motivation, Company B organized its supply chain in different levels, which differ in terms of the number of suppliers, length of relationships, level of spend, degree of collaboration, and how decision-making is carried out.

When arranging suppliers in different levels Company B is able to manage strategic aspects accordingly. Such a strategic view enables the implementation of different commercial policies and the development of contextualized managerial approaches. For example, 80% of Company B spend is concentrated in suppliers in the first and second level. Suppliers in the first and second levels are directly responsible for successful project delivery, given that a larger part of spend is concentrated in their businesses. Although suppliers at the third and fourth level do not receive a large share of Company B spend, they might influence in other aspects of project delivery, especially in terms of time and quality.

Factors that affect supplier base management include complexity of projects, specific technical conditions, and safety requirements, among others. In this sense, the task of managing the supplier base is very dynamic. It was found in the interviews that Company B encourages both top-down and bottom-up approaches for managing its supplier base. Thus, inputs from corporate and project levels are considered in decision-making regarding Company B's supplier base. On the one hand, the nature and complexity of the job to be done sometimes require local contractors (i.e. earthworks). On the other hand, the majority of issues influencing the exclusion of suppliers from Company B's supplier base refer to health and safety non-conformances.

In order to summarize and evaluate Supplier Base Management in Case Study 2, the following points are discussed:

- **Positive aspects:** supplier base management is embedded in Company B's approach for managing its supply chain. First, the adoption of different supplier levels enables the deployment of specific strategies for managing its supply chain. Principles adopted by Company B for categorizing its suppliers are considered as comprehensive. In addition, by devising strategies accordingly, Company B is able to allocate specific people to coordinate suppliers' levels appropriately. Second, the implementation of both a top-down and a bottom-up approach increases the level of engagement, once responsibilities are shared between different organizational ranks. Due to the intensity of day-to-day operations, it is important that people at the project level have increased autonomy when making decisions. Otherwise, there will be at least two major consequences: overload of activities at corporate level and critical delays affecting decisions at the project level. Ultimately, such consequences affect project delivery in terms of cost, time, and quality;
- **Recommendations for improvement:** recommendations regarding supplier base management are proposed in terms of the way the current structure is reviewed and the ability of Company B in capturing information from the market. First, the review of suppliers allocated in each of the existing levels is recommended to Company B. In addition, it is suggested that criteria for allocating suppliers in the levels be also revised periodically. Such a reviewing process ensures that supplier base information is always up-to-date, which might contribute directly and indirectly towards increasing Company B's competitive advantage. Second, Company B's lack of a structured 'supply chain radar'. By implementing such a radar, Company B would be able to identify potential suppliers proactively and to replace current low performers in its supply chain easily. It is recommended that alternative suppliers for critical trades be constantly monitored in the market, given that they could be used in contingency

plans. After identifying such suppliers, it is worthwhile to assess their financial and operational risks, in order to comply with Company B's requirements.

6.2.1.3 Category Management

Company B employs category management for managing high-value materials and services and consolidating them into groups. Company B categorizes such groups, also called key categories, according to risk, spend, and opportunity. For each category, there is a supplier register summarizing maximum and minimum contract values to be undertaken, geographical areas of operation, prime scope of works already delivered, examples of previous projects, key subcontractors of the supplier, past performance, and general comments to be addressed by Company B employees. Key categories are allocated in the following areas:

a) **Subcontractors:** there are 43 key trades in the subcontractors' area including the following: aluminium systems, brickwork, carpentry and joinery, drainage, gantries, scaffolding, steel sheet piling, and tunnel boring machines, among others. Each category has a different number of suppliers registered, which varies according to the availability of suppliers in the market, current and future demand for the specific trade, and complexity of the required service.

b) **Designers:** key trades in this area are concentrated in designers and consultants. Company B has consultants for supporting its decisions in terms of the following aspects: air, environmental, highways, marine, nuclear, rail, waste, and water. It is noticeable that consultants are classified by their expertise, and there is little overlap between consultants in different business areas of Company B.

c) **Materials:** there are 14 key trades in the materials area including concrete, electrical cables and components, fuels, personal protective equipment, rebar, and timber, among others. Suppliers of materials have to comply with strict standards for delivering, unloading, and loading materials on project sites. The standards indicate types of trucks allowed, health and safety guidelines, site entry procedures, site housekeeping, lifting operations, work at height, and protection of surfaces, among others.

d) **Plant and transport:** there are 8 key trades in the plant and transport area including commercial vehicles, company cars, plant and access and equipment hire, temporary accommodation, small tools and light plant hire, supplier graphical data, crane hire, and miscellaneous plant solutions and innovations. It is worth mentioning that power generators and office accommodation solutions are also included in this category. Suppliers in this category are those that provide essential infrastructure for carrying out works on site.

e) **Out-sourced services:** there are 7 key trades in the out-sourced services area including mobile phones and data devices, conference calls, corporate travel, site security, utilities (gas, electricity, and water), managed IT support, and certification of suppliers. Such external certification is carried out by an external party, which is highly specialized in assessing suppliers' worldwide and providing frequent reports regarding performance and financial risks from the supply chain.

f) **Facilities services:** there are 4 key trades in this area including pest control, washroom services, garment cleaning, and couriers. Suppliers in this category should comply with minimum operational standards, which are specified in service level agreements. Due to commercial sensitivity, information regarding service level agreements was not disclosed for this research.

g) **Agency staff:** there are 2 categories in this area including professional agency staff and labour hire. Due to commercial sensitivity, information regarding agency staff was not disclosed for this research.

Company B has a significant work in progress: to consolidate its categories across all its business areas (i.e. energy, nuclear, highways, and rail). Currently, there are technical requirements from each business area that increase complexity in managing categories due to their uniqueness and novelty. For example, while suppliers in the highways sector are well known and developed, suppliers for nuclear developments are under evaluation and additional time is needed for understanding technical requirements and to position them in a key trade.

Company B has three central motivations for adopting category management. First, the possibility of having a central database with relevant supply chain information. Second, Company B has the opportunity for assigning a specific set of people to manage trades. Third, by having a central database and expert managers allocated to each category, Company B is able to streamline its supply chain management process and achieve wide economies of scale. It is worth mentioning that prices negotiated and agreed with suppliers include delivery costs. As stated by one of the interviewees: *"everything we buy we buy with a delivered price"*. In this sense, Company B eliminates the need to be concerned about transportation of materials, equipment, and crews to sites.

In order to summarize and evaluate Category Management in Case Study 2, the following points are discussed:

- **Positive aspects:** category management is considered as well defined in Company B. Categories are classified according to specific criteria in the topics of risk, spend, and opportunity. Such classification provides a strategic background for understanding the suppliers' profile. The availability of information regarding categories is highly accessible, given that such information is available on a web-based system. The scope of information regarding each supplier is centred in the topics contract values, geographical constraints, scope of works, examples of previous projects, key subcontractors of the supplier, past performance, and general comments. The web-based system is periodically reviewed in order to provide updated information. Finally, the definition of specific people to manage each category provides better results, given people become experts in their field in commercial and technical aspects;
- **Recommendations for improvement:** risks are partially considered in category management. Financial risks are prioritized given that contract values are capped according to suppliers' financial assessment. However, operational aspects (i.e. production capacity, logistics) are partly considered. Although Company B has structured risk mitigation plans, they are highly focused on the project level. As suppliers in category management are those categorized at the corporate level, it is highly recommended that contingency plans be developed for each key trade. Such plans must include sourcing alternatives to be considered in different scenarios, such as supply disruptions. In addition, synergies between different business areas in Company B are not fully explored. For example, supply chain management processes between highways, water, and nuclear areas are not integrated. Such lack of integration is reflected in category management, in which some areas are more developed than the others. Finally, performance of categories is not measured individually. Thus, performance evaluation, comparison, and cross benchmarking between categories is not fully explored. It

is recommended that Company B consolidates performance evaluation of suppliers, so that performance gaps across categories can be identified. Such identification of gaps will enable the development of action plans supporting the development of suppliers. In addition, category management enables increased collaboration between suppliers for technological development. In this sense, it is recommended that people responsible for managing each category conduct collaborative forums to foster and capture innovative solutions across the supply chain.

6.2.1.4 Early Supplier Involvement

The level of involvement of suppliers with Company B has increased over the years. However, a high level of supplier involvement could only be obtained in specific contractual arrangements. Contract formats influence early supplier involvement directly, and they differ across clients and economic sectors. Even with to regard the same client, the characteristics of the contracts vary significantly, which is the case analysed in this research.

In the particular project evaluated in this research, the contract was awarded to Company B in 2011. Such early involvement enabled the involvement of Company B in the preliminary design and planning process of the project. It is worth mentioning that works on site were scheduled to start in November 2014, they will last for 2.5 years, and 60 suppliers will be involved.

It was found that early involvement changes the role of the contractor and consequently of the supply chain. Examples of critical suppliers considered for early involvement in Company B include earthworks, design partners, and traffic management technology, among others.

Mutual interests contribute to increased early supplier involvement. Interviewees reported significant interest in engaging in a particular typology of projects in order to increase its market share in governmental projects. In addition, one of its key suppliers showed significant interest in taking part in projects in the same typology. By integrating efforts, both Company B and the supplier developed collaborative actions in order to have a deeper understanding of the specificities of such projects.

The decision regarding which suppliers should be involved early is structured on different 'gates', in order to indicate critical suppliers. Some of the suppliers might be characterized as single sources, influencing the critical path of the program, or highly specialized. It was reported in an interview that it is up to 'bid team' discretion to select suppliers to be involved early in a particular project. For example, in the case of a single source, Company B goes to the market and checks whether new suppliers are available. In addition, single source suppliers also provide estimates regarding how prices will change in the future so that variation in costs can be foreseen:

> *"I like to think we are clever enough to foresee where there are going to be issues".*

It is the opinion of interviewees that financial gains regarding early supplier involvement are not high. However, the flow of activities in Company B is considered smoother in projects adopting such a strategy. It is reported by interviewees that such comparison is hard to quantify because *"you never build two roads that are exactly the same"*.

It is consensual among interviewees that *"the better information you get, the better you are going to perform"*. In this sense, suppliers should have access to relevant information, as soon it is available, including designs and BIM models. This information should also include geographical data (i.e. location of access to the site, soil characteristics).

It was found that more and more tender processes are decided by non-financial aspects. Company B interviewees' reported that in some cases (i.e. green field projects) there are special requirements. In one of the cases discussed, high capacity in the earthworks activities was explicitly required. Therefore, the supplier was involved since the beginning in pricing, quantifying, designing, and scheduling. Relevance of such early involvement was noted by one of the interviewees:

> *"these guys are the real experts in what they do… we are only the main contractor".*

It was also found that barriers for implementing early supplier involvement include the length of relationship with the supply chain. Last minute changes in specifications and unexpected variations in demand and capacity influence early contractor involvement significantly. In addition, regional aspects and past performance should be taken into consideration, as expressed by the interviewees:

"there is massive variance depending on geographical location… so, while you may have poor performance down in London, it doesn't mean they are the right people to be taken into the North West".

In order to summarize and evaluate Early Supplier Involvement in Case Study 2, the following points are presented:

- **Positive aspects:** Company B values early supplier involvement, given that such an approach helps to make processes smoother. In addition, the strategic alignment promoted by Company B towards its suppliers, in the sense that early supplier involvement is used as a common ground for achieving mutual objectives, is positive. Transparent communication and shared information regarding designs and BIM models also provide significant background for early involvement of the supply chain;
- **Recommendations for improvement:** the benefits generated from early supplier involvement should be captured in a different fashion. Although such early involvement is highly valued by interviewees, the creation of a register of accomplishments and tangible benefits generated by early involvement of suppliers is recommended. In this sense, Company B should implement a tool at both project and corporate levels that summarize developments in this topic. Company B should also engage with its peers and foster a change in the market, so that contracts are focused on early supplier involvement. The elimination of last minute changes in the scope of projects is suggested, especially those that affect early definitions in the supply chain. Finally, the decision regarding which suppliers should take part in early involvement should be better structured. Currently, the process is subjective and there is a lack of evidence supporting the decision. The adoption of additional tools appreciating objective criteria and increasing the participation of the project level in decision-making is recommended.

6.2.1.5 Supplier Development

Supplier development in Company B is widely focused on SMEs, especially those that are considered subcontractors. Currently, 60% of Company B's supplier base is composed of SMEs, who have difficulties in managing their business properly. It is the opinion of interviewees in Company B that suppliers have different levels of management maturity, which produces significant variations in performance across the supply chain. Due to its governance role, Company B decided to create a structured programme to tackle supplier development, which is called Supply Chain Academy (SCA).

During this research, it was noted that the Academy is in its fourth annual edition, and it comprises 15 suppliers per year on average. The Supply Chain Academy is composed of training modules in a range of disciplines, including the following but not limited to them: environment, health and safety, behavioural safety, lean construction, product development, BIM, equality and diversity, finance, innovation, and tax credits, among others. Performance of participant suppliers is not compared before and after they have joined the Academy.

In order to take part in the Academy, suppliers have to go through a selection process. Criteria for selection includes turnover (up to £8 million/year), number of employees (up to 50 direct employees), and motivation to become a member of the SCA, among others. Turnover and number of employees are assessed in order to make sure participant suppliers meet the European Union definition of a SME. Interviews are conducted to check whether the supplier is really focused on improving its business by accessing 'best-practice' and interacting with other suppliers that have different business environments. It is also preferred that suppliers have at least two years of direct or indirect business with Company B.

Company B has chosen to deliver the training sessions along with some of its strategic partners. Experts from Company B and partners are invited to deliver the modules, so that training excellence is assured throughout the program. Currently, training modules are delivered in a central location, which requires suppliers to travel in order to attend classes. After each module, an assessment is carried out in order to check to what extent delegates have acquired the appropriate knowledge. Suppliers are entitled to enrol two representatives in each module, and it is the responsibility of the supplier to nominate the delegates. The relevance of the SCA is acknowledged by interviewees, as stated below:

"the reason we do it is to give them the opportunity to have quality training, all provided free of charge".

Prior to joining the SCA, suppliers receive an introduction pack. This pack is a document of 12 pages containing the objectives of the Academy, statements from previous delegates, attendance rules, a full programme of activities, and detailed descriptions regarding the contents of each module. It is worth mentioning that the SCA is provided to suppliers free of charge.

In order to summarize and evaluate Supplier Development in Case Study 2, the following points are presented:

- **Positive aspects:** supplier development presents itself as well structured in Company B. First, the focus of development is centred on SMEs, who constitute a representative part of the supplier base. In addition, SME's lack managerial knowledge due to limited access to training. Second, the range of training sessions provided by Company B is considered as comprehensive, especially because it covers diverse disciplines. By using internal people and partners employees to deliver training modules, Company B has reduced costs in conducting its SCA. In addition, these people are expert on their areas and have increased perception of Company B strategic objectives, which guides the way in which modules are presented. Third, the process for selecting suppliers that will take part in the SCA is well structured, so that only SMEs are admitted. In addition, by including interviews in the selection process, Company B is able to communicate SCA objectives and to capture the real motivation of the supplier for attending the Academy. Fourth, the assessments taken after each module, which allow the verification of training quality are well conducted. In addition, the idea of letting suppliers choose delegates that will attend training sessions is valuable, as they have better knowledge of the skills of their own employees. Finally, the creation of an introduction pack presenting detailed information about the SCA is very positive, as it communicates the objectives and overall structure of the Academy;

- **Recommendations for improvement:** recommendations regarding supplier development in Company B are proposed in terms of the way training modules are delivered, the usefulness of information captured from SMEs along their development, performance evaluation, and lack of practical activities supporting training sessions. First, it is recommended that Company B engage with universities and educational institutions in order to enhance quality of training, by making them more robust in terms of theoretical aspects. In addition, it is suggested that online collaboration be increased, so that webinars enable the SCA to reach larger audiences and reduce travelling costs. Second, Company B acknowledges that its level of information regarding SMEs is low. Traditionally, the relationship with these companies has been purely transactional, as the majority of them are local suppliers. However, as Company B started to reduce and manage its supplier base closely, many of its SMEs became more relevant. Company B needs to capture accurate information from SMEs, such as their capacity, quality assurance procedures, and delivery times, among others. Third, improved performance of suppliers is not measured as a direct or indirect result of supplier development efforts. The development and implementation of performance measures to assess the level of evolvement of suppliers while they attend the Academy is suggested. Although it will not be possible to attribute their overall improvement to the Academy, it would be possible to assess at least their performance trend. As SMEs are not used to performance measurement, it is advisable that only a few metrics are measured in order to simplify the process. Finally, due to common SMEs limitations, it is complicated for them to put theoretical knowledge in practice. Although training modules are well presented in form and content, the shift from new concepts to day-to-day practice is not evident. In this sense, it is recommended that suppliers receive additional support. A hands-on consultancy approach focused on SME development is recommended as a supplementary action in supplier development. Primarily, such consultancy should be related to the contents of the training modules. In addition, consultancy sessions should be carefully synchronized, so that they take place just after a specific training module.

6.2.1.6 Performance Measurement and Benchmarking

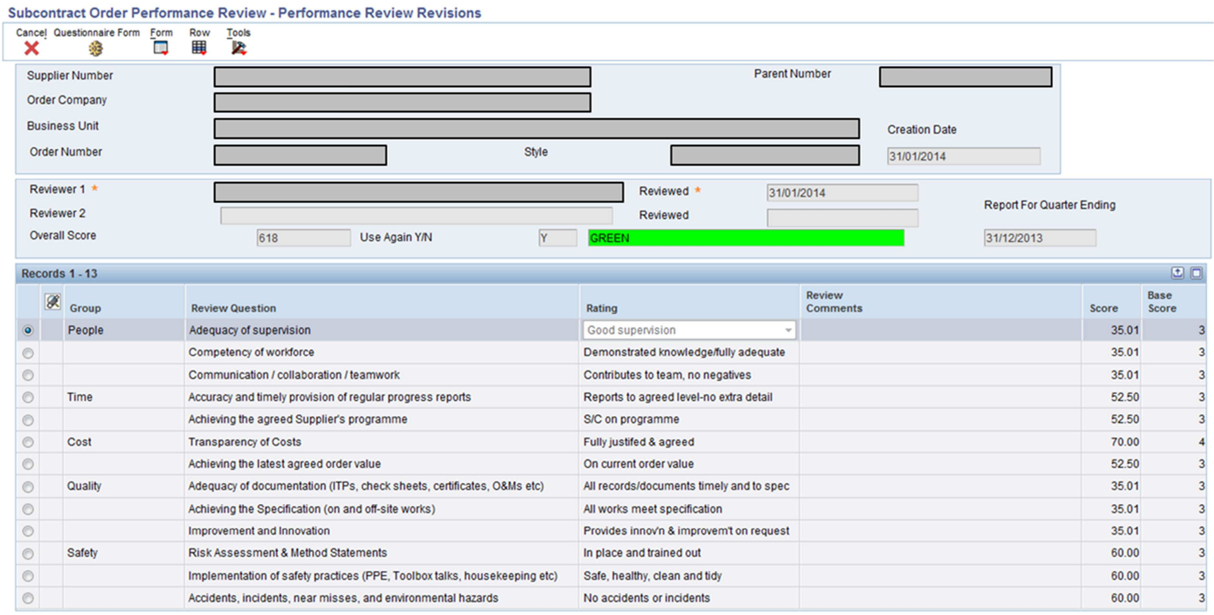
Suppliers are evaluated by Company B according to their financial relevance (i.e. amount of spend in a particular supplier). Typically, 80% of the overall spend is concentrated in 100 suppliers, which is constantly evaluated by Company B representatives. The majority of the top-100 is composed of subcontractors.

Evaluations are conducted on a quarterly basis and they are typically conducted by a Quantity Surveyor at the project level. During the evaluation, a representative of the supplier is also invited. Performance is then categorized according to four categories:

- Blue, which is attributed to suppliers that achieve 80% to 100% in the assessment;
- Green, which is attributed to suppliers that achieve 50% to 79% in the assessment;
- Amber, which is attributed to suppliers that achieve 25% to 49% in the assessment;
- Red, which is attributed to suppliers that achieve 0% to 24% in the assessment.

Evaluations are recorded in a web-based system. Suppliers must develop an action plan in case they are categorized as 'amber' or 'red' in the assessment. Information regarding suppliers' past performance is fully available across Company B, which refers to this register as a 'supplier profile'. The colour coding system described above is well known inside the company, and it is reproduced across the web-based system (as shown in Figure 44) and internal documents (i.e. spreadsheets).

Assessments are focused on five key groups: people, time, cost, quality, and safety. Company B defined different weights for the groups, and this weighting system is revised periodically. Inside each group, there are specific questions to be reviewed by the assessor and an appropriate rating to be attributed, as shown in Figure 44. In addition, there is space for relevant comments to be registered during the assessment.



Subcontract Order Performance Review - Performance Review Revisions

Cancel Questionnaire Form Form Row Tools

Supplier Number
Order Company
Business Unit
Order Number
Style
Parent Number
Creation Date 31/01/2014

Reviewer 1 *
Reviewer 2
Overall Score 618
Use Again Y/N Y
GREEN
Reviewed * 31/01/2014
Reviewed
Report For Quarter Ending 31/12/2013

Records 1 - 13

Group	Review Question	Rating	Review Comments	Score	Base Score
People	Adequacy of supervision	Good supervision		35.01	3
	Competency of workforce	Demonstrated knowledge/fully adequate		35.01	3
	Communication / collaboration / teamwork	Contributes to team, no negatives		35.01	3
Time	Accuracy and timely provision of regular progress reports	Reports to agreed level-no extra detail		52.50	3
	Achieving the agreed Supplier's programme	S/C on programme		52.50	3
Cost	Transparency of Costs	Fully justifed & agreed		70.00	4
	Achieving the latest agreed order value	On current order value		52.50	3
Quality	Adequacy of documentation (ITPs, check sheets, certificates, O&Ms etc)	All records/documents timely and to spec		35.01	3
	Achieving the Specification (on and off-site works)	All works meet specification		35.01	3
	Improvement and Innovation	Provides innov'n & improvem't on request		35.01	3
Safety	Risk Assessment & Method Statements	In place and trained out		60.00	3
	Implementation of safety practices (PPE, Toolbox talks, housekeeping etc)	Safe, healthy, clean and tidy		60.00	3
	Accidents, incidents, near misses, and environmental hazards	No accidents or incidents		60.00	3

Figure 44 – Screenshot of suppliers' evaluation template in Company B

It is also worth mentioning that projects in Company B have different characteristics (i.e. timeline, budget, technical complexity), but they have the same relevance when it comes to supplier evaluation. Overall performance of top-100 suppliers over 2011, 2012, and 2013 is illustrated in Figure 45. It is clear that performance of suppliers is very stable and it corresponds to 66.65% on average, which is inside the green category over the last 12 quarters.

Performance measurement in Company B is highly focused on subcontractors, mainly because 80% of spend is concentrated in outsourced services. In this sense, performance measurement regarding suppliers of materials is limited. Typical problems such as poor delivery and quality performance are considered infrequent by Company B representatives. Damages of materials during transportation or loading/unloading operations are reported as infrequent as well. However, Company B inspects specified materials rigorously (i.e. concrete tests and analysis), and non-conformances are registered in a booklet for further reference (i.e. development of action plans).

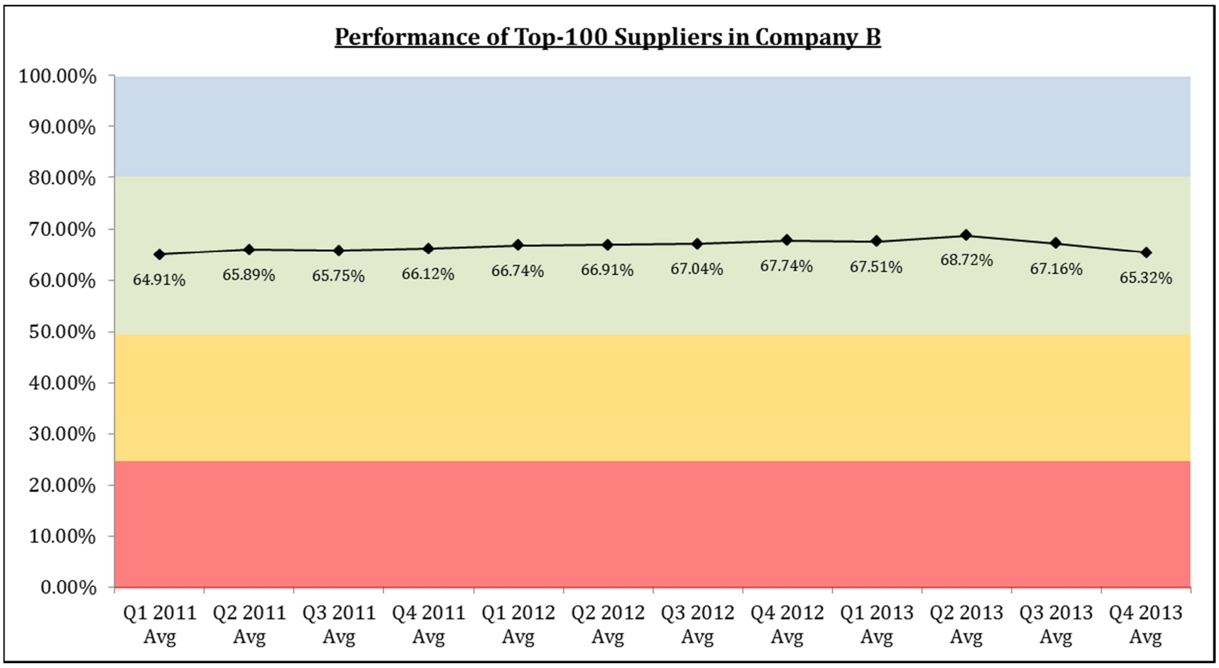


Figure 45 – Performance of Top-100 supplier in Company B

Performance of suppliers across different projects is consolidated and analysed. In order to provide and receive feedback, Company B organizes formal business-to-business meetings with suppliers, which occur twice a year for the top-100 suppliers. Company B keeps track of past and to-be scheduled meetings by using a spreadsheet.

Company B circulates information regarding overall performance of its top-100 suppliers frequently. Interviewees reported that by circulating such information they raise awareness regarding outstanding performance or eventual problems with a particular supplier. Company B compiles such information in a report and uses e-mails to circulate it between key personnel.

Typical problems reported by Company B in supply chain performance are concentrated in the following areas: last-minute supply chain disruption, changes of scope in project development (and consequent impacts on cost, quality, time), and health and suppliers' safety non-conformances. However, these problems are considered as 'normal', and Company B representatives affirm they can be easily solved, especially with suppliers with a long-term relationship.

In order to summarize and evaluate Performance Measurement and Benchmarking in Case Study 2, the following points are presented:

- **Positive aspects:** Company B has a structured measurement system to assess its supply chain performance over time. The system is balanced across different areas of evaluation (i.e. people, time) and the metrics used have different weights according to their relevance. Such a weighting system is reviewed periodically in order to keep alignment between Company B's strategic priorities and supply chain performance. Suppliers are evaluated according to their relevance in order to have a light measurement system. In this sense, the top-100 suppliers are formally evaluated on a quarterly basis. Past performance of suppliers is easily accessible via a web-based system and overall information is frequently compiled and circulated across Company B. A coding system, which uses different colours to indicate performance, is used across Company B. Such a coding system increases transparency and visibility for managing supply chain performance. Poor performance, classified in the system as 'amber' or 'red', is highlighted in a specific report so that further actions are required from suppliers;
- **Recommendations for improvement:** although Company B has substantial information regarding supply chain performance, benchmarking and collaboration between suppliers is limited. In addition, lessons learned in a particular project site are not easily captured and multiplied across the company. Although Company B has relevant information regarding project and supply chain performance, it misses an opportunity for improving its supply chain in a sustainable and systematic way. It is worth mentioning that 20% of Company B spend is concentrated on materials. In this sense, it is not recommendable to neglect performance measurement of such suppliers. On the contrary, it is advisable that Company B starts to monitor closely the performance of the suppliers of materials in terms of delivery, quality, and technical specifications, among others.

6.2.1.7 Procurement Scheduling

Procurement scheduling is an effort conducted at both project and corporate levels in Company B. As operations are project-driven, it is essential that both levels share information in order to synchronize on-site production, procurement, and off-site production performed by suppliers as well. In this sense, the result of the procurement scheduling effort produces implications not only within the company but also across suppliers. Company B allocates projects in a pipeline according to the bids. Typically, it takes between 12 to 18 months from the day Company B wins a bid to start work on site. During this period, coordination becomes crucial both at corporate and project levels, as highlighted in the words of one of Company B's commercial representatives:

"once a contract is awarded, we try and contact the site team to sit down with them".

At the corporate level, central procurement is responsible for aggregating information and specific demands from all project sites. Although this is a complex task due to the large amount of data, central procurement is not supported by an electronic system for aggregating and categorizing such data. In this sense, the major part of the activities relies on the experience of the employees involved. Central procurement is then responsible for negotiating work packages over £5,000. In addition, central procurement is also accountable for managing contracts with suppliers of high-profile items such as personal protective equipment, rebar, and concrete mix, among others. Although Company B acknowledges that *"the more time you have the better price you can get"*, it was found that at central procurement 80% of the activities are classified as urgent. Central procurement usually has 2 weeks for placing a purchase order or negotiating an agreement. After reviewing the lists containing all trades, vendors to be approached, and the work-packages produced by project level, central procurement provides instructions for the local team.

At the project level, the project manager is responsible for synchronizing the project's programme with procurement. In this context, detailed design is considered critical for starting procurement activities, and it was frequently referred to by interviewees as a 'bottleneck'. According to one representative of Company B, *"in our business you can't source something until you get the designs".* Bills of quantities are only available after the detailed design is complete, which enables a further stage in the process: cross-reference with specifications. By cross-referencing information, procurement will be able to start its process. Based on the bill of quantities, materials and services to be outsourced are then categorized. Such categorization is based on their intrinsic characteristics, the amount to be spent, and the date in which they should be available on site. Typically, it takes 5 to 6 months from obtaining detailed design and completing categorization of trades. It is worth mentioning that the quality of designs is critical for obtaining accurate bills of quantities. The team at the project level is also responsible for preparing lists containing all trades, vendors to be approached, and the work-packages. This information is forwarded to central procurement, at corporate level, for approval purposes. Rushed orders are not common at project level, and they represent no more than 10% of the total number of orders. Such rushed orders are typically concentrated in low-spend items demanded from changes of scope in a project. It was pointed out by interviewees that changes of scope are common in refurbishment projects due to increased uncertainty.

The integration between project and corporate level comprises suppliers too. The supply chain side is mostly concerned about the definition of milestones along the project by Company B, so that suppliers are able to plan production and prepare crews for mobilization in advance. By integrating project and procurement schedules, Company B enables the supply chain to plan the work ahead, which leads to decreased disruptions during project delivery.

Integration between project level, corporate level, and the supply chain is structured by a formal procedure. Such a procedure is designed so that all stakeholders have awareness of the steps and verifications that should be taken during the project. The procedure indicates a process 'by which a Contract is awarded to a Strategic Partner or a Preferred or Verified Supplier'. The process has well defined inputs (i.e. main contract documents, estimating, subcontractors' requests for quote), outputs (i.e. bid documents, risk assessment, contract documents), and a list of recipients of relevant information (i.e. bidders, project manager, procurement director). Low levels of disruption in site operations were reported by Company B, and such positive results were attributed to the adoption of this structured procedure, as shown in Figure 46.

It is worth mentioning that Company B uses 'gates' for managing its supply chain. Such 'gates' are used for checking whether relevant information is properly shared across corporate level, project level, and ultimately with suppliers. The checks comprise the consistency of data in spreadsheets with the bills of quantities, the up to date project schedule, and information regarding supply chain capacity, among others.

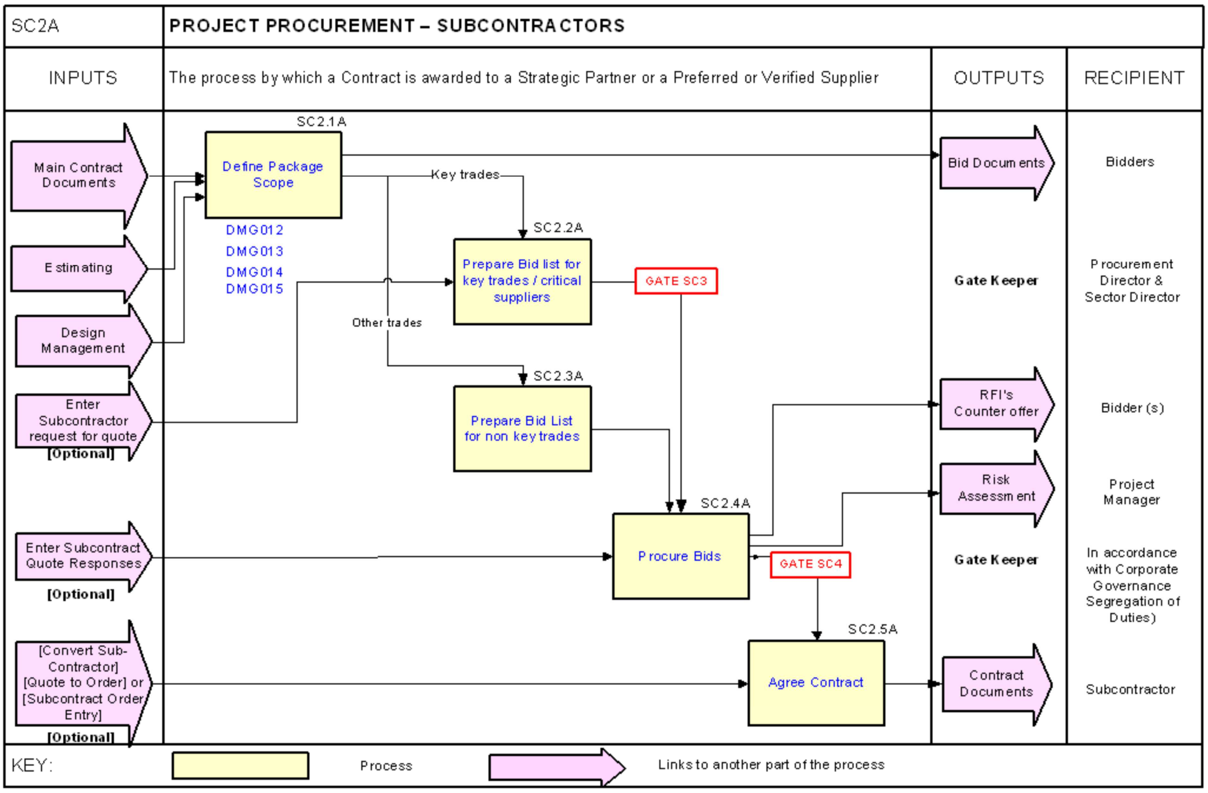


Figure 46 – Internal procedure in Company B

In order to summarize and evaluate Procurement Scheduling in Case Study 2, the following points are discussed:

- **Positive aspects:** procurement scheduling is well structured in Company B. High levels of integration between project and corporate levels were found. It is clear that such increased integration has a positive implication on the supply chain side, once low levels of disruption were reported by Company B. In this sense, project delivery has been as smooth as possible, especially in high profile projects such as infrastructure. Procurement has access to detailed information as soon as the contract is awarded, which enables collaboration and structured decision making across Company B. Collaboration between central procurement and the procurement team is high. In addition, the decision making process is shared between key stakeholders due to increased availability of information. Demand of materials and services is aggregated by central procurement, which produces significant economies of scale. Procurement scheduling also allows Company B to categorize work packages according to their risk and spend, so that central procurement has relevant information about critical trades. Procurement activities at the project level are not rushed, as indicated by the percentage of rushed orders reported by interviewees;

- **Recommendations for improvement:** the way demand is aggregated at central procurement is not ideal. Although Company B aggregates demand from different project sites, it can be estimated that less than 75% of the information is actually captured, given that central procurement is not supported by any software for doing so. In this context, it is recommended that Company B monitor its level of demand aggregation. Current IT systems in the market have powerful capabilities in capturing and aggregating information regarding demand. Even though procurement scheduling is well established, the levels of rushed orders at central procurement are very high. Increased levels of rushed orders can be attributed to the low level of employees in central procurement, which increases the number of orders to be processed in the queue. At the very moment they start to work in an order that is in the queue, it becomes rushed. In this sense, it is advisable that Company B reviews the workload of people at central procurement. There is significant waiting before detailed designs are prepared and available for procurement for quantity take-offs. Although 5 to 6 months are dedicated for the preparation of detailed designs, an amount of additional waiting due to changes of scope was reported by interviewees. Ultimately, such alterations affect procurement scheduling and consequently suppliers' production planning processes. It is recommended that the amount of waiting should be monitored, especially for including buffers across the project schedule. Additionally, the quality of detailed design should be critically evaluated so that rework due to poor specification is minimized. It is recommended that such a control system should be implemented by the project manager, as soon he or she is nominated.

6.2.1.8 Supply Chain Risk Management

Supply Chain Risk Management is carried out by Company B in two streams. First, there is a focus on the financial risks taken by suppliers. Second, there is a concern regarding operational aspects such as supply chain capacity.

First, financial risks are analysed for each supplier. In order to carry out an overall evaluation of suppliers, Company B uses a third-party firm to perform such assessments. This firm has worldwide access to different databases and it is able to deliver a comprehensive evaluation of the supplier considering different markets. In addition, Company B performs an annual spend review of the supply chain, to check if there are discrepancies between the risk assessment and the level of spend. More recently, Company B started to cap the amount of spend of specific suppliers in order to avoid problems. Although there is a pro-active behaviour in identifying risks, Company B has difficulties in managing risks, as stated below by one of the interviewees:

"I don't think we have an appetite for risk".

"it is not in our interest that suppliers go burst".

Although 'few surprises' are reported by interviewees, in some cases it is too late, and permanent damage is made to a supplier or project, as mentioned as follows:

"if you have a company (supplier) with a turnover of £7 million and you give them a contract of £10 million and it is going to be delivered let's say within the year… that is a problem, and this actually happened… and I said categorically, do not place that order with them… and they did, and they went burst".

Second, operational risks are analysed on a project basis. In this sense, critical suppliers involved in a particular project are assessed in terms of capacity, technical capabilities, and inventory levels, among others. The critical nature of works is considered also for aggregating work packages in the project. Natural risks are also taken into account in risk assessments (i.e. in a particular project evaluated in this research, earthworks, pavement, drainage were considered as critical). Company B used to keep more inventories on site in the past, but this approach has changed over the years due to just-in-time deliveries offered by suppliers:

"We used to keep a lot more stock, but deliveries these days are much better… we haven't got storage because of the cost … and … there is also the risk of damaging the materials".

Operational risks are also considered in relation to the programme as stated below. In this sense, Company B continually monitors projects' milestones and crosschecks information in order to avoid supply chain disruptions.

"in a package of £15 M… the supplier has access to the whole site as well as removing painting and repainting the structure … so initially, that access was critical to get the other trades up there such as steel fabrication… and they are critical again at the end of the job for painting it again and finishing it".

A 'Risk Management Plan' is developed for each project. Although the plan is developed at the project level, there are inputs from the corporate level. The plan is a formal document, which is reviewed by different executives across Company B. Such reviews are registered in a specific session named 'revision history'. The names of reviewers, approvals, and people in the distribution list are also recorded in the plan. It was sustained by interviewees that a key factor for developing a robust plan is to have the participation of the client in its development. Contents of the plan include:

a) **Executive summary** contains a brief description of the plan's scope and the definition of risk considered by Company B as follows: 'Within this document the term "risk" means the effect of uncertainty on the projects objectives – positive and/or negative'.
b) **Risk statement** comprises the areas of risk that should be analysed, mitigated, or eliminated. Such areas are proposed by Company B and by the client and they can be arranged in four categories: strategic risks, programme risks, centrally managed project risks, and project risks. A complex process for managing risks across the project is carried out, which contains numerous steps, stage gates for assessment, and production of reports, among others. Additional to the Risk Management Plan, the risk statement includes a template for the 'Risk Register' and 'Qualitative Risk Assessment'. Risks are classified as 'low', 'medium', 'high', and 'critical'. In addition, risks follow a colour scheme according to the respective management response for each classification. Figure 47 illustrates the management response to risks found in the Risk Management Plan for a particular project in Company B.

Risk level	Management response
Low	Tolerate but keep the risk under review Ensure adequate allowance included in cost estimates/risk allowances and programme plans
Medium	Manage/mitigate the risk as part of day-day project team activities and re-assess as risk register is updated. Ensure adequate allowance included in cost estimates/risk allowances and programme plans.
High	Focused senior project management attention is required to address the risk and seek to mitigate. Ensure adequate allowance included in cost estimates / risk allowances and programme plans.
Critical	Risk with high likelihood and having significant detrimental impact on achievement of project objectives which cannot effectively be controlled by project team. May require elevation to MPD senior management / MPD Programme Office

Figure 47 – Management response to risks in Company B

c) **Risk environment** comprises detailed information regarding project specifications, key constraints, key programme milestones and activities, and key stakeholders. The project analysed in this research involves the construction of 7.5 km of dual carriageway and moving 750,000 m^3 of earthworks. Community and environmental aspects represent the majority of identified constraints, including surveys for relocation of birds, high levels of ground water, and weather sensitivity due to the amount of earthworks, among others. Stakeholders include not only the client and communities, but also other contractors developing works across the same scheme.

d) **Roles and responsibility**, including names of people on the client's side and in Company B are listed according to their positions. Roles in risk management include risk owner, risk actionee, and risk manager. The risk owner 'is the contractual owner of the risk as stated within the conditions of contract and shall either state the Employer or the Contractor'. Risk actionee is the person that actually manages the activities by assessing, monitoring, and reporting the status of the risk. Risk manager is the one responsible for promoting and building a risk aware culture and 'reporting, escalating, and communicating risk management issues'.

e) **Risk management process** is composed of five different stages, namely risk identification, risk assessment, risk response, and risk reporting and review. First, risk identification is 'an iterative process' focused on capturing risks and analysing similar causes of risk and categorising a potential domino effect, among others. Identified risks should be included, quantified, and assessed in the risk register according to their actual development: pre-mitigation, mitigation, and post-mitigation. Identification includes a risk number, risk source, generic risk description, project specific risk description, risk type, risk category, and impact on the critical path. Second, risk assessment comprises analysis of individual risks, analysis of potential risk aggregation, and evaluation and prioritization. Analysis of risks might include several levels of detail depending on the risk and resources available. Aggregation should be done in order to identify appropriate conditions for grouping or splitting risks. Evaluation and prioritization include probability scoring (rare, unlikely, possible, likely, almost certain), cost impact scoring (insignificant, minor, moderate, major, catastrophic), time impact scoring (insignificant, minor, moderate, major, catastrophic), and quality impact scoring (minimal, minor, moderate, large, major). Third, risk response gives proper direction for risks by following one of the options: modify risk, transfer risk, tolerate risk, avoid risk, and seek risk. Finally, reviews and reporting include planning workshops and reports in terms of their target audience and frequency. The communication process is highlighted by interviewees: *"to integrate everyone's risk … I think one of the big things is to communicate what risk each part holds from day one"*.

f) **Appendixes** in the plan analysed included a 'Sample risk register', 'Standard risks prompt sheet', 'Sample risk detail sheet', and 'Risk categories'. These sample documents were reviewed as part of the research process.

Figure 48 illustrates how risks are positioned and categorized by Company B in the Risk Management Plan.

PROBABILITY >75%	Almost Certain 5	5	10	15	20	25
20-<75%	Likely 4	4	8	12	16	20
2 to <20%	Possible 3	3	6	9	12	15
0.02 to <2%	Unlikely 2	2	4	6	8	10
>0.02%	Rare 1	1	2	3	4	5
	IMPACT	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
CRITICAL RISK						
HIGH RISK	Cost	< 0.5%	0.5 to 1%	1 to 3%	3 to 5%	> 5%
MEDIUM RISK	Time	< 1%	1 to 5%	5 to 10%	10 to 20%	> 20%
LOW RISK	Quality	Minimal	Minor	Moderate	Large	Major
	Reputational	Public criticism of less than one day requiring minimal additional press office involvement.	Public criticism of over one day to one week and/or requiring a project team response.	Public criticism of over one to two weeks and/or requiring a significant project team response.	Public criticism of over one to two weeks and/or requiring a Chief Executive response.	Public criticism over three to four weeks and/or requiring a Secretary of State response.

Figure 48 – Risk ranking/prioritization in Company B

In order to summarize and evaluate Supply Chain Risk Management in Case Study 2, the following points are highlighted:

- **Positive aspects:** the process of managing risks is well established in Company B. It should be emphasized that both financial and operational risks are considered in risk management. The adoption of a third party firm for conducting financial assessments is highly recommended, given its comprehensive access to information. The annual review of spend is a positive practice, including the use of mechanisms that cap the size of contracts where relevant. On the side of operational risks, the concerns about capacity, technical capabilities, and inventory levels should be highlighted. The risk management plan is well structured in terms of the consideration of stakeholders, risk management process, prioritization of risks, and reporting structures;

- **Recommendations for improvement:** the level of integration between risk management and central procurement should be increased, given that in some cases contracts are awarded even when there are financial risks. Although the risk management plan is comprehensive, it should include specific contingency plans for critical trades. Such plans should specify suppliers that have the potential to replace another one already in use. In the plan evaluated in this research, the majority of the actions for risk mitigation are concentrated on creating inventory buffers for materials and allocating additional hours to subcontractors to be used if necessary. Such actions are reactive and should be replaced by improved planning and control approaches.

6.2.1.9 Fragmentation Management

As Company B operates in a fragmented environment (i.e. multiple project sites, diverse suppliers), there are important practices adopted by the company in order to minimize such problems. Concerning supply chain management, fragmentation is managed by people at both the project and corporate levels.

Interviewees pointed out that there is a need to separate operational procurement (i.e. project level) from corporate management (i.e. strategic environment). This is justified by one of the interviewees:

"because there is job to do… in the daily management … in the localized supply chain".

The local team at the project level has ownership and autonomy to make decisions, given that daily activities on site are very demanding. Getting the supply chain on board is the first task carried out by the project team, which requires coordination with the corporate level as well. Such coordination is essential so that strategic aspects and sensitive information can be checked by directors. The project level is able to access past performance of suppliers by accessing internal databases. Given such information is centralized, the quality and availability of it is increased significantly. In order to reduce fragmentation, the scope of activities regarding supply chain management is well defined at project level, which includes contracting subcontractors, managing rentals, and purchasing low spend materials.

The organogram of people on site differs across the projects in terms of quantity and profile. It was found that some projects require a large number of experienced people due to their intrinsic complexity. Criteria for selecting people to work on a particular project include availability (people available in the area), opportunity (new positions), and internal and external recruitment. When questioned about the integration between project and corporate level, interviewees replied:

> *"it is very much controlled in terms of the requirements, the quantities… the assessment of what you need is on the site level and it is channelled to a central hub with quite a lot of other stuff".*

Concerning the number of suppliers, each project has on average 60 work packages to be contracted with subcontractors, and additional materials to be purchased. Large spend is directed to the corporate level, which is applicable to earthworks, concrete, and steel, among others that are negotiated on a national basis. At the project level, it is possible to contract local suppliers, as stated by one of the interviewees:

> *"it is not completely rigid, there are new people in the supply chain to subcontract… if it is suitable according to the geography of the job, maybe getting a local supplier might be better".*

It was found that local suppliers are managed on a temporary basis. Their selection depends on project location, given that certain regions have increased options and others present reduced availability of suppliers. There is no minimum number of local suppliers to be contracted in particular scheme.

At the project level, the team needs to check the level of accreditation of suppliers, which is provided in reports by a third party. This external firm provides relevant information from a national database, which is used by major organizations in the UK. Company B has been using such an accreditation system since 2012.

It is not common to transfer materials between project sites in Company B. Although there are no central warehouses, the availability of materials is considered as very good by interviewees. Deliveries are carried out by suppliers and materials are delivered just-in-time at project sites, which contributes to reduced inventory levels. Debris and packages are recycled on site on a regular basis. Demobilization is coordinated by the project team, and it should be completed as quickly as possible (i.e. within 3 to 4 weeks).

In order to summarize and evaluate Fragmentation Management in Case Study 2, the following points are presented:

- **Positive aspects:** fragmentation management is well conducted in Company B. The clear definition of scope regarding activities at corporate and project levels should be underlined. The autonomy for decision-making given to the project team is very positive, since it helps to expedite actions and ensure the development of activities on site. The availability of information related to suppliers' past performance contributes to reducing fragmentation across the supply chain. The adoption of a third party firm for supporting suppliers' accreditation should also be stressed as a positive aspect in fragmentation management, given that structured reports are distributed across Company B;
- **Recommendations for improvement:** the level of integration between corporate and project levels should be increased. It was verified that such integration is ad-hoc, given that there is no structured format or a regular calendar of meetings. In this sense, it is highly recommended that specific and periodic forums be organized by Company B. Such forums can be arranged on a quarterly basis and have a detailed agenda concerning supply chain management at corporate and project levels. Representatives of key projects should attend such a forum.

6.2.2 Learning Cycle of Case Study 2

Case study of Company B assessed a set of practices for designing and improving construction supply chains. In addition, aspects concerning the conceptual framework proposed in this research were indirectly reviewed.

First, it should be delineated how Company B manages its supply chain. Although all projects are in the infrastructure sector, they present unique characteristics. There are multiple and concurrent projects, which are geographically positioned across the UK. Such projects vary in size, scope, technical specifications, economic sectors, and level of complexity. There is a specific and independent structure, in which an appointed project manager is responsible for the project once the contract is awarded. Supply chain management comprises activities at the project level that should be coordinated with the corporate level. Naturally, suppliers are also present in the 'supply chain environment', which add up to 1,200 companies in the supplier base. There are more than 1,000 suppliers that are classified as 'unverified', which are not taken into account directly in the supplier base. There are interfaces between the corporate level, projects, and suppliers. Such interfaces are interconnected by flows, especially those concerning information, materials, and capital.

Second, two practices should be underlined in terms of contributions to the existing set of practices. On the one hand, Performance Measurement and Benchmarking demonstrated a significant influence in assessing supply chain performance over time. The set of measures adopted by Company B is well balanced and periodically reviewed. In addition, such measures consider the relevance of suppliers, use a colour coding system, and are accessible via an online system. However, benchmarking and collaboration between suppliers and across projects is limited. The observation of performance concerning suppliers of materials is recommended. On the other hand, Supply Chain Risk Management considers financial and operational aspects consistently. There is an annual review of spend, concerns regarding capacity, technical abilities, and inventory levels. A range of stakeholders is considered in risk management. The development of specific contingency plans for critical trades and the elaboration of actions focused on proactive planning and control of risks is recommended.

Third, the contribution of Case Study 2 in terms of original practices to be incorporated in this research is relevant. Procurement Scheduling brings the idea of synchronizing projects' schedule and activities in procurement, so that the supply chain is able to get on board effectively. Category Management proposes an approach for categorizing materials and services systematically, which provides direct and indirect contributions. Supplier Development suggests the focus on a training scheme, which can have reduced costs when internal people are used for delivering training modules. Supplier Base Management includes the proposition of different levels of suppliers, which are categorized in terms of risk, spend, and opportunity. Long-term Supply Chain Governance comprehends the continued view of the supply chain, which encompasses actions that sustain development over time. Fragmentation Management deals with the intrinsic fragmented environment in Company B, by defining roles, responsibilities, and structured processes to integrate suppliers and the internal teams at corporate and project levels. Early Supplier Involvement encompasses the procedures that should be adopted in terms of direct collaboration, communication, and information sharing across supply chain.

6.3 Case Study 3 – Report

Company C is a governmental organization in the UK. The organization is responsible for operating, maintaining, and improving infrastructure assets. Such assets have major implications not only in social but also in economic aspects. Maintenance and improvement works are delivered by a complex supply chain. Maintenance contracts are named as Network Delivery and Development (NDD) and improvement schemes as Major Projects (MP). On the NDD side, suppliers typically have a five-year contract, which corresponds to one of the 12 specific areas of the network. On the MP side, suppliers have a specific contract for each scheme. The original idea of having a government organization as a case to be studied was motivated by its intrinsic role. The public sector in the UK is responsible for 40% of demand in the construction sector (LEK 2012). Particularly, Company C is key for the development and continuity of heavy infrastructure contractors, especially because of the expansion of its assets' network. In addition, Company C can be studied from a different perspective: a client that has a special governance role that pushes the market towards improvement and fosters the development of contractors' supply chains.

Case Study 3 was carried out in Company C from August 2013 to August 2014. Empirical research involved Company C and six of its tier-1 suppliers, which are major companies in the UK construction sector. Representatives from the lean and continuous improvement division, procurement, and supply chain departments within Company C were approached. In addition, six suppliers of Company C participated in this research. The selection of participants to be interviewed and to be invited for meetings was conducted by Company C. Criteria such as area of expertise, availability, time for completing the study, and levels of confidentiality of information were considered in the decision. The suppliers were also appointed by the government organization based on the following criteria: financial impact, location, overall performance, and time limitation for completing the case study. Their representatives were formally invited by Company C to take part in this research. Although suppliers involved in this case study are major contractors in the UK, they are not the focus of this research at this stage. Both the representatives from Company C and from the suppliers were mostly in senior positions.

Case Study 3 comprised interviews, participation and observation of meetings, and collection of documents. Documents were archived physically and digitally in order to support the findings of this research. The meeting observed was related to a specific group of suppliers that work together with Company C for improving their overall performance. This meeting was observed exclusively to assess its implications in the referred improvement process. Table 24 summarizes the activities developed.

Table 24 – List of meetings and interviews in Case Study 3

Item	Activity	Participants
1	Meeting	Company C employee, Representatives of 3 suppliers
2	Meeting	Company C employee, Representatives of 3 suppliers
3	Meeting	Company C employee, Representatives of 3 suppliers
4	Internal Workshop	Company C employee, Representatives of 3 suppliers
5	Meeting	Company C employee, Representatives of 3 suppliers
6	Meeting	Company C employee, Representatives of 3 suppliers
7	Interview	Company C employees (3)
8	Interview	Company C employees (3)
9	Interview	Company C employees (2)
10	Interview	Company C employee
11	Observation of Meeting	Company C employees (3), Representatives of 4 suppliers
12	Data Validation (NDD)	Company C employees
13	Data Validation (MP)	Company C employees

The selection of practices to be assessed was based on the scope of activities, relevance of achievements, and availability of information to be provided. The activities of Case Study 3 were concentrated in assessing the following practices:

- Long-term Supply Chain Governance;
- Supply Chain Strategic Alignment;
- Early Supplier Involvement;
- Supplier Development;
- Prequalification of Suppliers;
- Category Management;

- Supply Chain Performance Reporting Review.

6.3.1 Practices Investigated

The following sections present the practices investigated. For each practice a detailed report of the findings and feedback regarding points to be improved is given.

6.3.1.1 Long-term Supply Chain Governance

Company C is responsible for a significant share of infrastructure investments in the UK. In order to deliver such investments, the organization has a complex supply chain of contractors and consultants delivering its projects on time, on budget, and on quality. However, Company C has faced difficult supply chain challenges in the past, and it will face more of them in the future, there is an explicit need for overall improvement. In this context, the long-term supply chain governance is discussed.

Discussions regarding governance appeared directly and indirectly during interviews with internal personnel and suppliers. The background of discussions dates back to 2011, when new procurement guidelines, practices, and procedures were proposed. Topics such as strategic management, suppliers' involvement and development, and best practices, among others, became more frequent in the business agenda.

Concerning the way Company C's supply chain is formed and managed, one of the interviewees stated:

> *"how do we, as a government organization with the tier-1 suppliers, decide what is best to put on our network… again, the experts are the framework suppliers, they should be in there having those discussions".*

Company C has primarily tier-1 and tier-2 suppliers. At the moment, there are approximately 30 tier-1 main contractors delivering schemes across the UK, supplied with materials and services provided by tier-2 contractors. Surrounding this environment, there are technical consultants, and Small and Medium Enterprises (SME). The idea is to increase collaboration and innovation between all the actors involved.

Learning from the supply chain has been an early inspiration for Company C representatives interviewed in this research. Sometimes, the supplier can propose solutions that generate better value, which is a key objective of Company C, as exemplified by one interviewee:

> *"'a supplier can say 'don't put that down, it will cause you a nightmare, it will last for five years… if you put this down, it will cost you a little bit more, but it will last for ten' … and you haven't spent twice as much".*

In its governance role, Company C realized that working close to the suppliers is more important than working constantly over time with them. A close relationship with the supply chain *"gives us … the confidence that we are working with the right suppliers who want not to just get their own money, but they want to help"*. In this sense, Company C decided to prioritize long-term relationships with supply chain. When questioned about the relevance of long-term relationships in managing supply chains, one interviewee replied, *"when I say long-term alliances I don't mean working with them for a long period. I mean shaping the supply chain so they are heading the same way we are".*

The shape of the supply chain referred to above is central in the governance discussion. Although Company C and its suppliers are independent companies, they have their business interconnected within the same sector. Thus, the way Company C foresees future government and social demands for infrastructure investments should be clearly aligned with its supply chain. Given the pipeline of future projects in the next 15 years, defined as *"a massive program of works"*, it is crucial to make sure suppliers will be ready for the challenges ahead and *"bring suppliers up to speed"*. In this context, a key aspect to be checked is how suppliers are planning their own development as a business. In the past, Company C was more concerned about how suppliers were delivering the projects, which can be defined as concern in terms of supply chain capability. Now, such concern has shifted from supply capability to supply chain alignment, as stated below by different interviewees:

> *"we want to change the focus (of suppliers) from capability to aligning with the way the company wants to do things…".*

> *"more transparent… so we can see how the costs are… we can see the best way of doing something… so we get common practices and common standards from the whole supply chain…"*

> *"… it also gives the suppliers the chance to look at their business as a whole and see what they can improve'".*

Currently, Company C has a number of working groups looking at different topics in supply chain management such as capacity, responsiveness, and lean. However, there are still limitations regarding a key variable for improvement: the pipeline of projects. Although Company C has a long pipeline of projects, they are funded on an annual basis, which produces significant impacts on supply chain visibility. Such an implication derives from that fact that only projects to be developed within 12-months' time are confirmed. In order to solve this problem, new approaches are currently under discussion, but they would require external approval (i.e. subject to legal requirements) to be implemented.

It is the opinion of the interviewees that Company C is the leading government organization in terms of practices to managing its supply chain, mostly *"because we deal with bigger projects… so our processes need to be more robust"*, as stated by one of the interviewees. In this context, Company C has focused its activities on external benchmarking.

However, Company C heavily supports benchmarking and performance assessment of suppliers as *"we take the performance of our supply chain very seriously… and the system is designed to motivate them and move them on forward"*. Next developments related to supply chain governance include the consolidation of communities of suppliers inserted in a framework. The idea is that frameworks comprise a set of projects to be delivered, and suppliers will work collaboratively in this environment:

> *"we have to operate more like a community with the suppliers within the framework… we have more opportunities to discuss their needs".*

In order to summarize and evaluate Supply Chain Strategic Alignment in Case Study 3, the following points are presented:

- **Positive aspects:** the governance role performed by Company C is not capital-driven. Although Company C is a major customer in the UK construction sector, the company emphasizes its governance role on the improvement side. Thus, not only Company C realizes benefits from its supply chain, but also suppliers, consultants, and the entire construction industry in the UK. The inclusion of tier-2 suppliers and SMEs is a positive topic to be highlighted, given that these suppliers are typically neglected in the construction industry. The establishment of long-term partnerships with suppliers is also highly noticeable;

- **Recommendations for improvement:** the governance role of Company C should be studied in detail and referenced as a benchmark, so that other sectors are able to benchmark against it. In addition, there is a need to capture best practices across the supply chain in a structured way. The creation of a template for capturing such practices will enable wider supply chain improvement, as a bigger number of suppliers will have access to this information. The number of schemes organized in frameworks should be increased, so that amplified collaboration is achieved between Company C and its suppliers.

6.3.1.2 Supply Chain Strategic Alignment

In 2011, Company C developed and implemented a structured approach for evaluating how its tier-1 suppliers keep strategic alignment with Company C. This approach was called Strategic Alignment Review Tool (StART), which replaced the former Capability Assessment Toolkit. In 2011, Company C moved from the capability assessment perspective to a strategic viewpoint in order to assure supply chain development for the future. In its first round, StART evaluated 25 suppliers in total.

StART was developed in collaboration with representatives of industry and its current version is underpinned in the following areas for alignment: leadership, collaboration, supply chain management, delivering value, diversity and inclusion, and sustainability. The aforementioned areas are reviewed over time, which means that current areas might be removed or new areas might be added in the future. Company C has two main requirements for defining an area in StART: (i) the area needs to have a strategic nature and (ii) the area should not be evaluated in other assessments. First, the choice of areas with a strategic nature is evident, given that StART is a tool for supporting the corporate strategy of Company C. Second, the overlap of other existing tools with StART would implicate in increased waste, and therefore areas covered in other assessments should not be included in StART. The key actors involved in StART are the Project Manager responsible for the supplier, the StART lead nominated by each supplier, and the assessors. Two assessors are designated for each assessment: at least one of the assessors is from Company C, and in some cases an external party (i.e. a representative from a consultancy firm) is invited as an assessor. The StART process is divided into 9 steps:

- Attend briefing;
- Agree visit schedule;
- Complete preparation document (overview and agenda);
- Distribute documents to assessors;
- Review preparation documents and prepare for visit;
- Review/agree visit agenda;
- Carry out visit (capture key points for report, and initial score not shared with the supplier);
- Review draft reports (check consistency and finalise individual reports);
- Distribute reports to suppliers.

From the initial briefing to the assessment visit, the process takes 6 weeks. All the suppliers are assessed on an individual basis, and they receive separate reports. As initially agreed with suppliers, their particular performance cannot be released to the other suppliers involved (i.e. they see each other's results, but individual results are not identified). The distribution of reports occurs 2 weeks after all suppliers are assessed, and the consistency of the marking process is checked. Practices considered 'best-in-class' in each area of assessment are highlighted.

In order to prepare for the assessment, suppliers are allowed to have external consultancy support. However, on the day of the assessment, the presence of external parties is not allowed. The timetable for the assessment visits fulfils one working day. For all six areas the following items are allocated in the agenda: 20 minutes for the presentation of evidence by the supplier, 30 minutes for interview/question and answer, and 20 minutes for private discussion, agreement, and documentation of key points by the assessors. At the end of the day, after all six areas were assessed there are 30 minutes for final questions and comments. Suppliers consider preparing for the site visit *"very stressful"* and they refer so StART as "*it is like preparing for a tender"*.

Table 25 summarizes the areas for alignment, the strategic principles related to each area, and what Company C will look for in its suppliers' assessment.

Table 25 – Areas for alignment in StART - adapted from (Company C documentation)

Areas for alignment	Strategic Principles	What the company will look for
Leadership	Suppliers should work with the company to fulfil the strategic agenda of Company C. Suppliers should engage with the company for the long term and at all levels.	**Show to Company C what you do to support this principle, how you know that it works, and what you do to maximise its value.**
Collaboration	Suppliers need to work in close partnership with Company C in collaboration. Key elements: to promote sharing and openness to build trust, manage risk, and drive value.	
Supply Chain	Suppliers should develop the understanding, capabilities and working practices of their own internal and external supply chains in order to deliver effective results consistent with the strategic agenda.	
Delivering Value	Suppliers should mobilise all their talents and resources to deliver smarter and more efficient ways of working, for example through innovations and lean process improvements.	
Diversity and Inclusion	Suppliers should draw on the talents of the widest labour market and to ensure their employment policy and practice assures equality of opportunity and treatment.	
Sustainability	Suppliers should deliver better products and services which have reduced environmental impacts, have cleaner, more efficient production processes with negligible waste. Suppliers should take due account of people's different needs and of the impact on the health and well-being of local communities.	

Company C does not have a specific questionnaire for conducting StART. The company believes that asking predefined questions to the suppliers might inhibit or bias their responses. In this sense, different questions might be asked to suppliers in the StART process, even though it was stated in interviews that those questions are *"almost the same"*. One of the interviewees pointed out that *"we want to give suppliers an opportunity to tell us what they are doing".*

StART has a specific scoring system as presented in Figure 49. Each area is evaluated in 3 sections, namely Fit, Function, and Value. All areas have the same weight. The sections contain 2 sub-sections each, totalling 6 sub-sections in the evaluation process. First, the Fit assessment is conducted. At this point, the assessors evaluate and mark appropriately the level in which what the supplier does (i) clearly addresses Company C principles, and (ii) keeps in tune with the principles of Company C over time. Fit scores are coded as A (i) and A (ii), which add-up to A. Second, the Function assessment is conducted. At this point, the assessors evaluate and mark appropriately the level in which what the supplier does (i) is embedded into the supplier's culture and (ii) is assessed and routinely reviewed and improved. Function scores are coded as B (i) and B (ii), which add-up to B. Third, the Value assessment is conducted. At this point, the assessors evaluate and mark appropriately the level in which what the supplier does (i) is exploited to its full potential for both the supplier and Company C, and (ii) sets the supplier apart from everyone else. Value scores are coded as C (i) and C (ii), which add-up to C.

StART Scoring Chart

Fit: the assessors' confidence that what the supplier does ...	None/very low	Limited	Moderate	Good	Very good	Exceptional		Fit Score:
... clearly addresses Highways Agency principles	0	1	2	3	4	5	A(i)	A(i)+A(ii)
... keeps the supplier in tune with Agency principles over time	0	1	2	3	4	5	A(ii)	**(A)**

Function: the assessors' confidence that what the supplier does ...	None/very low	Limited	Moderate	Good	Very good	Exceptional		Function Score:
... is embedded into the supplier's culture*	0	1	2	3	4	5	B(i)	B(i)+B(ii)
... is assessed and routinely reviewed and improved*	0	1	2	3	4	5	B(ii)	**(B)**

Value*: the assessors' confidence that what the supplier does ...	None/very low	Limited	Moderate	Good	Very good	Exceptional		Value Score:
... is exploited to its full potential for the supplier and the Agency*	0	1	2	3	4	5	C(i)	C(i)+C(ii)
... sets the supplier apart from everyone else*	0	1	2	3	4	5	C(ii)	**(C)**

TOTAL SCORE for Indicator= (subject to top-down sense-check)	**(A + B + C)** (Max Score 30)

Top-Down Sense Check

Limited Alignment*	Committed to Alignment*	Comprehensively Aligned*	Leading the Agency*
Bottom quartile	Second quartile	Third quartile	Top quartile

* Terms with asterisks are defined in glossary

Scoring factor | Scoring element

Figure 49 – StART score chart in Company C

The sub-sections can be marked as none/very low (0), limited (1), moderate (2), good (3), very good (4), and exceptional (5). Each sub-section can reach a maximum of 5 points, and therefore the maximum number of points per area is 30. All sections and sub-sections have the same weight. After the area is marked, a top-down sense check is performed according to four quartiles. First, if the score is in the bottom quartile, the supplier is considered to have a limited alignment in the particular area. Second, if the score is in the second quartile, the supplier is considered as committed to alignment. Third, if the score is in the third quartile, the supplier is considered as comprehensively aligned. Finally, if the score is in the top quartile, the supplier is considered as leading by Company C. As there are six areas in StART, the maximum number of points per supplier is 180. It is worth mentioning that the scores represent exclusively the level of alignment between suppliers and the strategic plan of Company C.

Although suppliers are scored, StART is not about performance. On the contrary, the key point of StART is to monitor and improve supply chain alignment. As stated by one of the interviewees, *"we can see things they wouldn't necessarily pick upon on a day-to-day basis"*. When the assessment process is finished, the suppliers are ranked. Such ranking of suppliers is published on the website of Company C, and therefore it is in the public domain. In 2011, 25 suppliers were evaluated in StART. After grouping their scores in four different quartiles according to the maximum number of points per supplier, it was found that five suppliers (20%) can be considered as leading by Company C, given that they reached more than 135 points. Seventeen suppliers (68%) scored between 90 and 135 points, and they were positioned in the third quartile. Three suppliers (12%) scored between 45 and 90 points, and they were positioned in the second quartile. None of the suppliers scored points in the bottom quartile. Scores obtained in StART influence prequalification and selection of tier-1 suppliers by Company C. According to one of the interviewees, top performers in StART *"are more likely to do a better job"*, although low performance in StART means *"suppliers are not strongly aligned"*. Finally, it was found that a limited number of suppliers requested a business meeting to discuss in detail their performance in StART. This group of suppliers is the one composed of the top performers.

In this research, only the first StART cycle was evaluated. Currently in 2014, a new cycle is under development and results are expected after the conclusion of this study. In order to summarize and evaluate Supply Chain Strategic Alignment in Case Study 3, the following points are discussed:

- **Positive aspects:** StART provides a structured and transparent approach for ranking and comparing suppliers. Such comparison is useful in decisions related with the tendering process (i.e. rank the suppliers bidding for a project and incorporate their StART scores for doing so). StART demonstrated a capability for enabling benchmarking, given that the suppliers have access to the reports of the other participants, and they might find potential practices to be incorporated in their companies. Given its structure, StART proved also to be effective in providing feedback for suppliers concerning strategic planning. The idea of having external assessors is interesting for reducing potential bias in the assessment. Finally, the way in which StART was designed facilitates the achievement of its core aim: to assure strategic alignment with the supply chain. Although this research has evaluated only the first cycle of StART, the practice proved to be robust for aligning strategic areas with suppliers. In summary, benefits of StART are realizable because *"lots of suppliers came to us after the assessment … and told us how it has been helpful for their business";*

- **Recommendations for improvement:** although StART is currently under its second cycle, there is no pre-defined period (i.e. within every two years) for starting new cycles. The definition and scheduling of specific cycles might facilitate the way in which suppliers organize their processes for future assessments. In addition, it will set a deadline for eventual improvement efforts. Company C decided not to attribute weights to the different areas, and considered such areas as having the same relevance. Although such a decision facilitates the scoring process, changes in the business scenario might influence the level of relevance of the areas. In this sense, one area might become more important when compared to the others. The attribution of weights to the areas via a structured weighting system is highly recommended. Company C has also not defined a set of expected tools, techniques, and practices for each area. Such a definition might be helpful for setting minimum standards in the supply chain. In this sense, during the assessment Company C would have the opportunity for assessing at what level the pre-defined tools, techniques, and practices have been implemented by the suppliers. In addition, the suppliers would also have the opportunity for presenting innovative solutions that might be incorporated to the above-mentioned pre-defined set of tools, techniques, and practices. A forum for presenting management innovation captured in the supply chain might be designed in order to foster collaboration between and acknowledge innovative suppliers. Finally, Company C does not request the suppliers to improve or maintain their performance in the further StART cycle. In this sense, it is recommended that suppliers have specific targets to be achieved in the subsequent assessment. Such targets can be reached based on actions defined by the supplier and supported by Company C, which can be formally registered in a collaborative action plan.

6.3.1.3 Early Supplier Involvement

Company C fosters Early Supplier Involvement (ESI). However, two central limitations for implementing this practice in full should be highlighted: the funding principles and EU regulations. First, Company C is funded on an annual basis, as previously stated, which constrains the availability of information regarding future demand. Second, the EU procurement regulations require that limited contact with suppliers is authorized before tender.

Even though the current process for tendering takes approximately 6 months, the level of involvement with suppliers could be better. The level is restricted, mostly because suppliers are not allowed to discuss the schemes in detail. It is the opinion of the interviewees that *"this prevents the development of the supply chain"*.

In this context, the potential of ESI is not explored in total by the company. The idea of sharing details and technical information (i.e. technical drawings) in order to study better solutions, and therefore generate increased value, is limited. New types of contracts, in which suppliers are organized in frameworks, enable some level of early involvement so *"the contractor will actually work with the company at the early stage to develop the design"*. Although this approach is applicable only to high profile projects, the level of information available is restricted in order to protect the characteristics of competition. ESI is based on strategic guidelines specified in internal documents, and it refers to the nature of the project. Currently, it is the opinion of the interviewees that suppliers are closer to Company C than before due to the creation of the aforementioned frameworks. According to interviewees, currently it is less common to have projects advertised individually. In the frameworks, there are tier-1 suppliers that deliver a program of works (set of projects) supported by designers, tier-2 suppliers, and SME's altogether.

Company C is now proposing a Collaborative Development Framework (CDF), to commence in October 2014. The CDF will be structured so that 3 different categories of programs (set of schemes) are created. Such categories will be classified according to their amount of spend. CDF is designed for increasing collaboration between suppliers, given that they will work together within a program. It is the opinion of interviewees that CDF will bring better value for the whole program of works based on increased collaboration. By increasing interaction between suppliers, Company C will enable a *"new way to deliver projects"*. The CDF will provide pipeline visibility of 5 years.

In order to summarize and evaluate Early Supplier Involvement in Case Study 3, the following points are presented:

- **Positive aspects:** although the company does not have an increased level of ESI due to legal restrictions, its awareness regarding the benefits of this practice is high. The creation of frameworks to increase collaboration by making suppliers work side by side is recommended;
- **Recommendations for improvement:** given the benefits regarding the CDF approach, it is highly recommended that Company C increase the participation of this approach. First, CDF fosters early supplier involvement and therefore innovation and collaboration across its supply chain. Second, the approach will increase supply chain visibility dramatically (from 1 year to 5 years).

6.3.1.4 Supplier Development

Company C has supplier development embedded in its culture, especially after lean was implemented inside different departments and across its supply chain. Company C adopts an active approach, in the sense that its employees and suppliers representatives engage together in cross-functional improvement initiatives. By adopting this approach, the company not only contributes to its own success but also makes significant impacts in the industry as a whole.

Roads Academy (RA) is an initiative promoted and funded by 30 companies in the roads sector in the UK. At the beginning, RA was an initiative promoted by the Major Projects directorate in Company C in order to increase supply chain collaboration and leadership. Such an initiative aims at developing future leaders in the sector by developing their interpersonal skills. Roads Academy is based on a structured approach that comprises a training scheme and the development of an internal consultancy project. On average, more than 50 delegates participate in the Roads Academy per year, which generally has 35% of employees from Company C. The training scheme is carried out during 15 months, which mainly cover behavioural topics. Internal consultancy projects are carried out during 9 months after the initial training schemes, and they should be focused on improving a determined business process or area. Generally, the financial aim of the projects is to gain or to save £ 1 million. Such projects might involve different organizations within the roads sector, ranging from customers to suppliers. After completing both the training scheme and the internal consultancy project, participants of the Roads Academy are awarded by an external organization with the postgraduate certificate in leadership and management. In order to take part in the Roads Academy, delegates should be approved in a selection process comprised of four stages: (i) Nomination and application, (ii) Application review, (iii) Attendance at the assessment centre to be interviewed, and (iv) Final Selection. Such applications are reviewed by an external organization that is responsible for the training schemes and provides technical support to the Roads Academy. Only organizations that are members of the Roads Academy are entitled to nominate people for the selection process. Typically, the participants take 24 months for completing the training scheme and finishing the internal consultancy project. Benefits realized in the RA include the following but they are not limited to them:

- Increased collaboration and team work, given that delegates work together in improvement projects;
- Improved leadership skills, which contributes to developing executives for the roads sector;
- Significant waste elimination and cost reduction across the supply chain.

Company C also supports the development of Small and Medium Enterprises (SME). The SME action aims at improved communication and elimination of barriers so that more SMEs take part on the projects of Company C. In this sense, Company C has created a 'direct channel' to communicate with SMEs, as part of a government directive to increase the participation of such companies in the competition for public sector contracts. The StART programme, detailed in section 6.3.1.2, also fosters supplier development because it provides structured feedback to suppliers on a regular basis. The nature of the program is to achieve increased strategic alignment with tier-1 suppliers, which also requires suppliers at this level to develop their own suppliers (tier-2). In this sense, Company C is streamlining its supplier development initiative across the supply chain. Finally, the implementation of organized performance measurement systems enabled supplier development as well. Feedback is provided to the supply chain based on recent performance, giving the suppliers also the chance to report suggestions of improvement to the company.

In order to summarize and evaluate Supplier Development in Case Study 3, the following points are presented:

- **Positive aspects:** constant collaboration with suppliers is achieved, which facilitates the exchange of knowledge and market information across the supply chain. The preparation of future executives for the roads sector is also very positive, once they apply their expertise across different companies as their careers evolve. In this context, both organizations and people realize clear benefits of supplier development. The structure of the Roads Academy, which is based on academic training and internal consultancy projects to be developed by delegates, is also very positive. First, the academic background provided helps to improve participants' expertise and leadership. Second, it creates a collaborative environment to foresee, implement, and realize cost reduction benefits across the supply chain. Initiatives such as SMEs action, StART, and the Motivating Success Toolkit (MST) foster the development of the supply chain as a whole. The development process establishes an opportunity to set the bar higher and push supply chain improvement;
- **Recommendations for improvement:** the way internal consultancy projects in the Roads Academy are monitored can be reviewed. The adoption of clear objectives and the establishment of targets to be achieved might be helpful for those conducting the projects. In addition, the level of SMEs development is still incipient. The proposition of a structured training scheme followed by dedicated consulting support to SMEs might bring powerful results to the supply chain of Company C. Such an approach might be funded by the entire supply chain, given that many of tier-1 and tier-2 suppliers have the same SME's in their supply chains. It is also recommended that Company C increases its level of involvement with universities, given that those institutions have resources to support such initiatives. Although Company C carries out the aforementioned activities for developing its supply chain, the way they communicate with suppliers is very fragmented. Such fragmentation is not realized internally, but it was reported by some of the suppliers during the research process. Fragmentation can be

attributed to the way Company C is organized: many areas and departments take care of different supplier development initiatives. In this sense, some improvement in communication might be achieved by increasing the synergies between the departments concerning supplier development.

6.3.1.5 Prequalification of Suppliers

Company C complies with European Union (EU) Procurement Regulations. In this sense, the company publishes frequent notices in the Official Journal of the European Union (OJEU) regarding its schemes, so that construction companies become aware of future projects to bid. There are specific deadlines for suppliers to submit their information.

Prequalification of suppliers is directly related to the individual notices published in the OJEU, which means prequalification is carried out on a project basis. Thus, each scheme to be developed by the company and to be bid for by contractors has an individual prequalification process. The process is directed to tier-1 suppliers, which means they take full responsibility for the project, including the selection of tier-2 suppliers.

Company C decided not to have an approved list of suppliers because *"we want to keep the competition as open as possible"*. Given recent changes in the world economy, especially in Europe, new suppliers from Spain, Portugal, and Ireland started to participate more frequently in the prequalification process.

In the case of high-profile projects or schemes demanding innovative technology, Company C carries out a pre-market engagement. Such an approach comprises different types of events (i.e. webinar, supplier day) depending on the target audience. Although there is no established process for identifying new suppliers in the market, the company uses pre-market engagement as a means to raise awareness about its critical projects. Normally, 80% to 90% of bidding suppliers are already in the supplier base.

Prequalification of Suppliers normally takes seven weeks per scheme. However, the duration of prequalification varies significantly as the number of participant suppliers increases because *"when an OJEU notice goes out, we don't know how many suppliers will apply"*. Rework can be found in the prequalification process, mainly because new suppliers need special attention, as they do not know the details of the prequalification process because *"maybe the procurement pack is not as clear as it should be… that is why* *we've done this lean project*". Internal lean-based improvement projects have been developed over the last year in order to simplify and standardize information to suppliers. According to one of the interviewees, when Company C improves its internal processes *"suppliers understand what we want and give us what we want"*. The amount of waiting in Stage 2 is significant, since some reviews from external referees are delayed. Finally, it is argued that the size of contracts and the way schemes are organized *"do not encourage SMEs to take part"*.

Prequalification of Suppliers is divided into two stages, namely Stage 1 and Stage 2. Stage 1 is more important because it covers all areas of prequalification, and the company carries out Stage 1 regardless of Stage 2. The amount of information required from suppliers is classified in 'packs' according to the level of spend and risk in a particular project. Three categories of 'packs' currently exist in Company C, which are described below and illustrated in Figure 50.

- Pack for goods and services, which require reduced evidence to be provided. Typically, this pack is designated for those projects with low spend and low risk;
- Mini Pack, which comprehends a set of different pieces of evidence to be provided for either high risk/low spend or low risk/high spend schemes;
- Full Pack, which is required for complex schemes involving high risk and high spend.

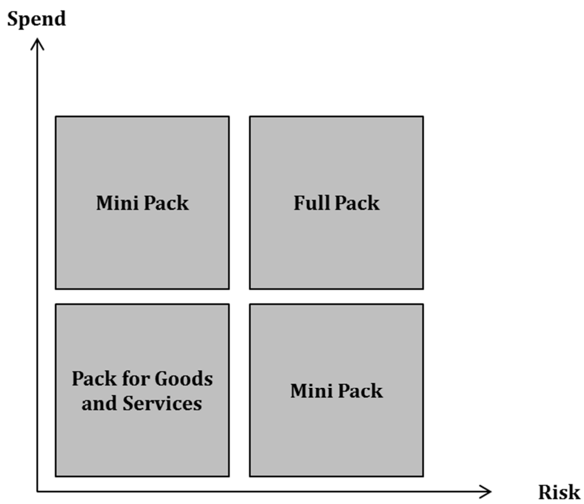


Figure 50 – Risk *vs.* Spend analysis in prequalification of suppliers

Stage 1 is mandatory and its outputs are classified as 'pass or fail'. Suppliers are supposed to send the respective pack of supporting evidences and legal documentation as requested by Company C according to the risk *vs*. spend analysis. Company C fosters the adoption of publicly available certification, especially those in the construction sector. Such certifications indicate that suppliers meet minimum requirements, which can also be extended to suppliers' suppliers. One of the interviewees argues that certificates *"reduce the burden for companies in the repetition of prequalification"*. Although Company C recommends the use of third-party databases for selecting and prequalifying suppliers, they argue that sometimes such databases are

> *"'best-practice, but they are too generic… and they should be analysed in parallel with additional information".*

Stage 1 includes a basic check of suppliers' technical abilities, financial status, and health and safety practices:

a) The assessment of **technical abilities** is based on a questionnaire, in which relevant questions for a particular project are picked from a generic database containing approximately 30 questions. Suppliers must also provide reference contracts so that technical abilities can be verified with external referees.

b) **Financial status** is checked in order to verify whether a supplier is stable enough to bid for a project. Such assessment is performed by external auditors, especially Construction Line. In the case suppliers are not registered with Construction Line, Company C requires relevant financial information related to the previous 5 years. Regular financial checks are performed by external auditors on behalf of Company C. The list of suppliers bidding for high a profile scheme is typically reviewed by Company C's board of directors, so that they can check any conflict of interest or strategic issue.

c) **Health and Safety** aspects are checked annually, and approved suppliers receive a certificate. High performers use the certificate as a marketing strategy, since health and safety is a top-priority in the supplier selection agenda. Assessments are performed by representatives of the company and external auditors, which carry out their auditing process based on site visits. Suppliers know upfront when and how they will be assessed.

Stage 2 is performed as a request of Company C and it typically includes five suppliers. The purpose of Stage 2 is to support the selection process and help Company C to short list suppliers for the tendering process. At this stage, past performance of suppliers is now considered when available. Such past performance is verified inside the company (i.e. past performance of projects developed for the company) or outside (i.e. past performance reported by contractor's customers). A vendor rating regarding past performance is designated to each supplier as the main output of Stage 2. Attributes composing the vendor rating include traditional project measures such as cost, time, right first time, among others. Contractors shortlisted in Stage 2 should also inform Company C to what extent they can provide better value for the particular project they are bidding on. Communication with suppliers is based on an electronic platform, which has been referred to by one of the interviewees as:

> *"a data centre, where we upload the documents… all communication happens through the procurement office on our side… so there is no communication with our suppliers outside (the platform)".*

Stage 2 also considers the scores of other evaluations including StART (Strategic Alignment Tool), which is explained before in section 6.3.1.2. It is the opinion of interviewees that the use of scores is helpful to reduce subjectivity in the supplier selection process. The output of Stage 2 is the shortlist of approved suppliers to be reviewed by the procurement director, and then suppliers will be invited to tender.

In order to summarize and evaluate Prequalification of Suppliers in Case Study 3, the following points are discussed:

- **Positive aspects:** the adoption of a 2-stage process is highly recommended, given that suppliers can be properly evaluated at the right time. In addition, the promotion of pre-market engagement is also a positive aspect, since it increases the level of communication with the market and with the supply chain. Risk *vs.* spend analysis is adopted in a positive way when it is used in areas such as prequalification. The classification of suppliers in categories according to risk and spend is helpful for organizing the level of information required from the supply chain. The adoption of external auditors, referees, and organizations that certify determined practices is also relevant. In terms of subjectivity, the adoption of score-based systems to evaluate and categorize suppliers has proven its applicability. Finally, the use of an electronic platform for compiling information during prequalification is highly recommended, as it increases transparency and organization in the flow of information;

- **Recommendations for improvement:** although the areas of technical abilities, financial status, and health and safety are included in prequalification of suppliers, there are critical aspects not covered. There is limited evaluation of suppliers' capacity and flexibility, and site visits are exclusively used for health and safety assessment. In this sense, one can argue that assessments are focused only in some aspects, which leads to reduced consideration of operational features. Although there are European Union regulations to be considered, it is very unproductive to prequalify suppliers on a project basis, once the level of repetition of activities is very high. Levels of waste (i.e. rework, waiting) have been reduced, but they are still present in the prequalification process. Lean-based projects aiming at reducing waste are highly recommended for mitigating or eliminating waste in this environment. Consultation of existing databases containing suppliers' information is limited, even though there are acknowledged companies providing relevant and reliable information in the UK. It is recommended that such databases should be incorporated in the prequalification of suppliers when available, as an additional source of information. Finally, an active identification of suppliers in the market was not found. On the contrary, the company is very reactive in this sense given its specific business characteristics. The implementation of a structured approach for monitoring the market and identifying potential suppliers is recommended.

6.3.1.6 Category Management

Category Management Framework (CMF) is an approach started by Company C in 2011. CMF has two explicit objectives:

- To reduce costs of projects by generating economies of scale;
- To increase collaboration and innovation between suppliers across the supply chain.

However, before demonstrating how the aforementioned explicit objectives are developed, some details regarding CMF should be highlighted. Currently, Company C has five categories, namely Pavement, Gantries, Temporary Traffic Management, Earthworks, and Traffic Technology. CMF is focused on tier-2 suppliers in order to capture their contribution for increasing tier-1 competitive advantage. The number of items within each category varies significantly. In order to create a new category, a number of steps are undertaken, including the following but not limited to them:

- Analysis of key areas of spend;
- Assessment of areas to check which ones have more structure to form a category;
- Check and validation with senior executives regarding the potential categories to be developed;
- Creation of a Category Delivery Plan containing the following topics: market evaluation, strategic analysis, cost reduction forecast, suppliers' list, and pipeline of potential schemes, among others;
- Validation of the Category Delivery Plan with senior executives;
- Creations of contracts with suppliers.

Pavement is the most active category, given its number of competitions. Currently, new categories are under analysis including Road Stripes, Ducting, Drainage, Fencing, and Sewerage. A key limitation for developing and implementing categories is the short length of planning horizons in Company C. A firm pipeline of schemes can be foreseen up to 12 months in advance due to a central reason: the company is funded on an annual basis. Another challenge in expanding CMF is that tier-1 suppliers are not used to foster early supplier involvement with tier-2 suppliers. One of the interviewees pointed out that

> *"… we are losing the advantages of early contract involvement somehow"*.

A key solution pointed out by Company C to enable early supplier involvement in CMF is the expansion of the planning horizon from 1 year to 5 years. However, this change will only be possible after altering the funding mechanism in the company. It is worth mentioning that the adoption of category management within the company was highly inspired by the automobile sector, aiming at increased efficiencies across the supply chain. A central motivation of CMF is to increase the level of awareness in Company C regarding its supply chain activities, as stated by one of the interviewees:

> *"obviously … we are trying to get to know what is going on in tier 1 and tier 2 suppliers, that is why we are going forward with the category management framework".*

The objectives of category management are:

a) **Cost reduction** is a key objective of CMF. Information regarding the pipeline of future projects is organized so that quantities of materials are aggregated from all schemes, and organized according to respective categories. By aggregating demand from all schemes within a 1-year forecast, the company is able to consolidate higher volumes of materials, a key enabler for generating economies of scale. Tier-2 suppliers are then approached and negotiations for each material start according to the amount of information available in the pipeline. Commercial aspects such as the price of materials and payment conditions are then compared, so that the tier-2 supplier providing better value wins the competition. The information is now registered and tier-1 suppliers have access to the relevant information according to the scheme they are bidding on. Tier-1 suppliers are free to quote the materials with other suppliers, but they should by necessity consult the CMF register to check commercial conditions. Although it is not likely, in the case tier-1 suppliers find better prices outside the CMF, they are authorized to purchase the materials. It is worth mentioning that CMP competition is scheme-based, which means tier-2 suppliers compete many times across different schemes. Items within each category are all catalogued, so that competition is directed by Company C. A maximum price is attributed to each item, also called ceiling rate, to be also catalogued for each material later. Registered prices are annually adjusted according to pre-defined indexes related to the market.
b) **Collaboration between suppliers** is also a key objective of CMF. The communities of suppliers are formed within different frameworks in the respective CMF categories. Suppliers in the frameworks have early access to schemes information, which help them to work towards improvement (i.e. technical development of solutions, geographic-optimized capacity allocation). Suppliers are able to look at designs and discuss potential solutions for problems

or improvement actions earlier. In this sense, suppliers are able to say *"don't design like that … if you design like this, not only will it work better, but we'll be able to deliver it and build it for you quicker, therefore cheaper, more efficiently and it will last longer".* Sometimes, problems regarding the programme are also discussed (i.e. shortage of materials) and solutions are provided (i.e. duplicate the 'bottleneck' by increasing capacity) in the CMF, so that the project will not be delayed. However, it is the strategy of Company C that *"suppliers work together to a certain point"*, so that there is no conflict of interest. The way Company C capture best-practices and lessons learned within each CMF is still incipient: there is a huge opportunity to cross-analyse the lessons learned in each community and schemes and use this information as a database for further reference.

Company C believes that CMF has its two key objectives interconnected, as *"it is not about saving money as such, it is about making sure that we are going to get the program delivered on time and on budget… and if there are some savings along the way that is an additional bonus".* Company C also foresees implications of CMF in its supply chain sustainability, since less consumption of materials is incentivized. This new perception has implications on the carbon footprint of Company C, as emphasized by one of the interviewees:

> *"it costs us £20 less because we are buying more of it… that is easy… it is not in question to save £20,000 pounds, but if we can save 20,000 tons… it becomes sustainable procurement… and I think the communities are more inclined to save, for example 20,000 tons…"*

In order to summarize and evaluate Category Management in Case Study 3, the following points are presented:

- **Positive aspects:** the actual implementation of CMF has proven to be a powerful strategy to monitor the prices tier-1 suppliers are paying in the market. In this sense, category management consolidates its first contribution: capture relevant information from the supply chain. It is also interesting the way CMF increases demand visibility to both tier-1 and tier-2, as suppliers are able to foresee the pipeline of projects. However, in order to produce improved results, the pipeline's visibility should be expanded over 12 months. It is also very common to find tier-2 suppliers neglected when it comes to supply chain management. However, the way Company C engages with their suppliers' suppliers (tier-2) in the long run is definitely a positive aspect from CMF. The notion that better value is an output of the work developed by suppliers in the communities is also positive, especially because such outputs are periodically (every 4 to 6 weeks) reported in the community board meetings;

- **Recommendations for improvement:** operational aspects are not prioritized in CMF, such as the alignment of future demand and capacity. Once future demand is known and increased collaboration is achieved in the supply chain, the task of matching supply and demand should be quickly carried out in order to minimize disruptions. Second, the way in which category management is currently conducted is based on spreadsheets, which is very time consuming and imprecise. Therefore, it is highly recommended that an automated system should be adopted. The implementation of an electronic system will also tackle the current CMF difficulties in capturing the achievement of its core objectives: financial savings and best-practice generation. In addition, an electronic system will also allow Company C personnel to cross-reference information from different categories and assess CMF's performance. Third, CMF is directly affected by the way schemes are organized within the company, which commonly isolates one scheme from each other. By isolating schemes in the MP and NDD side, the company misses the opportunity to take advantage of synergies between those different areas.

6.3.1.7 Supply Chain Performance Reporting Review

Company C has a complex program of schemes, which are delivered by different contractors. In order to keep track of performance of project delivery, Company C developed a measurement system to assess supply chain performance. The way in which the system is designed has a central premise: suppliers must report their performance systematically.

As the program of projects is complex, the aforementioned performance reporting system is also complicated. According to the existing directorates, there are different requirements for MP and NDD schemes due to their intrinsic nature. While MP schemes are a one-time project, NDD is on the maintenance side of the business, which has specific items to be monitored.

However, the creation of a performance measurement system requires periodic review. Such review is necessary because past conditions that influenced the inclusion of metrics may have changed. In addition, changes in the business scenario might influence the way metrics are measured as well. In this context, the practice investigated in this section is the review of supply chain performance reporting, adopted by Company C for the first time.

Internal procedures and guidelines regarding supply chain performance reporting in Company C were reviewed. Data was collected from four suppliers, two on the MP side and two on the NDD side. For MP projects, metrics are concentrated in the areas of cost and time. On the NDD side, metrics monitoring the impacts of weather conditions are predominant. It was found that Company C has 67 Key Performance Indicators (KPI) measuring each MP scheme and the majority of them are reported on a monthly basis. Data from suppliers indicates that 165 hours/month are required for capturing, analysing, consolidating, and reporting such KPIs every month. When this study was undertaken, there were 11 MP schemes running. Findings also indicate that Company C has 81 KPIs assessing the performance of each NDD area. The majority of NDD metrics are also reported on a monthly basis by suppliers, which provided date indicating that 401 hours/month are dedicated to capturing, analysing, consolidating, and reporting KPIs every month. When this study was conducted, there were 12 NDD areas active. Table 26 summarizes key figures of supply chain performance reporting in Company C.

Table 26 – Summary of hours spent in performance reporting

Description	MP	NDD
Number of KPIs per scheme	67	81
Hours/month per scheme	165	401
Number of schemes	11	12
Total number of hours/month per directorate	1,815	4,812
Total number of hours/month	6,627	

By reviewing the above-mentioned amount of hours, which correspond to more than 6,500 hours per month in performance reporting, the direct and indirect impacts of this process are clear. It is worth mentioning that financial data were available at the time of this research, but due to the sensitivity of information, they are not disclosed. Such a decision does not produce any harm to this study. In this context, a question was raised by different Company C and suppliers' representatives:

"How to make supply chain performance reporting (PR) leaner and better aligned to the achievement of organizational goals?"

There were two central concerns at this point. First, the level of alignment between current KPIs and the company's business scenario was questioned. Second, the extension in which KPIs were adding value to both the company and supply chain was examined. The above-mentioned question guided the next steps developed by Company C.

First, five areas of competitive advantage to be analysed were selected from the literature: Cost, Dependability, Flexibility, Quality, and Speed. One additional area was also proposed due to the requirements of Company C: Environment, Health, and Safety (EHS). Evidence and drivers from strategic documentation were linked to these six areas in order to rank them as competitive drivers. In addition, each KPI was classified in one of the six areas of competitiveness. By matching the six competitive areas with the actual KPIs in MP and NDD, a misalignment was found. While strategic documentation indicated a pattern, it was found that MP and NDD present a low level of adherence to this rank. Table 27 illustrates the differences of priorities across Company C's strategic documentation, and MP and NDD performance measures.

Table 27 – Ranking of competitive priorities

	Company C	**MP**	**NDD**
Cost	4th position	1st position	3rd position
Dependability	1st position	2nd position	2nd position
EHS	2nd position	4th position	4th position
Flexibility	5th position	6th position	1st position
Quality	3rd position	3rd position	5th position
Speed	6th position	5th position	6th position

The analysis of the ranking of competitive priorities answers part of the question raised earlier in this section. Competitive priorities were ranked from 1st position to 6th position, which means from more important to less important respectively. The supply chain of Company C is currently spending a vast number of hours in performance reporting, but what has been reported is not aligned with current Company C business scenario. Justification for that was consensual between Company C and suppliers' representatives: the performance reporting system is not periodically reviewed as strategic documentation is. Therefore, the gap between the company's priorities and what has been actually prioritized is noticeable. To make performance reporting better aligned, Company C needs to know the gap between its current business scenario and actual performance measures. Next, Company C needs to review its performance measures so that they are better balanced between priorities, and therefore better aligned.

Second, in order to answer the second part of the question, the company and suppliers' representatives were asked to classify each KPI on the MP and NDD side. A template was developed so that participants have the list of relevant KPIs to be classified. The classification was divided into four categories:

- (0) Low;
- (1) Below average;
- (2) Average;
- (3) Above average.

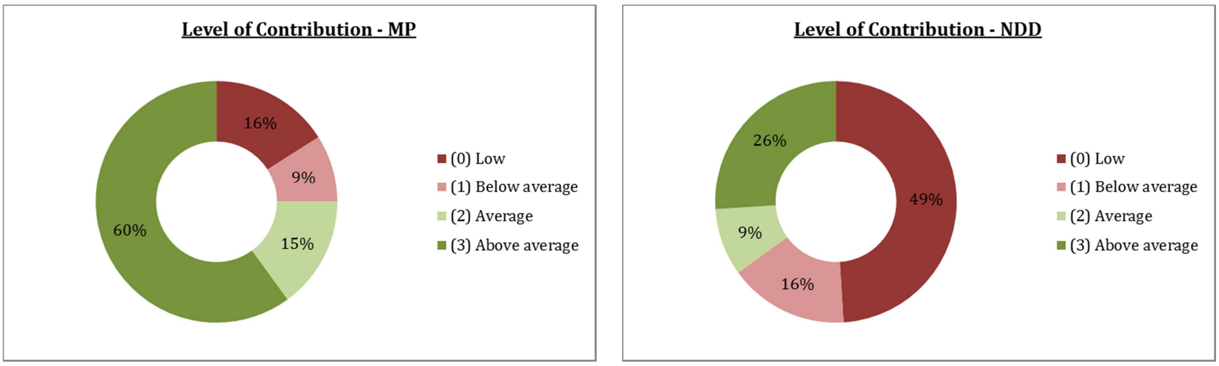


Figure 51 – Level of contribution of KPIs

Company C and suppliers' representatives classified the 67 KPIs on the MP side and the 81 KPIs on the NDD side. The objective was to assess how participants perceived the level of contribution of each KPI to performance reporting. On the one hand, KPIs classified as 0 and 1 were considered as non-value adding. On the other hand, KPIs categorized as 2 and 3 were considered as adding value to performance reporting. Figure 51 indicates the results.

Assuming that the hours spent in performance reporting spread evenly across different KPIs, the following analysis was carried out. This analysis was based on the information shown in Figure 51. It is noticeable that MP has 25% of the KPIs classified as non-value adding, which adds up to approximately 453 hours of performance reporting classified as waste. On the NDD side, this number is worse: 65% of the KPIs are classified as non-value adding, which adds up to approximately 3,127 hours. The non-value adding hours for MP and NDD were also categorized according to the six areas of competitive advantage. Such categorization was carried out to check how balanced non-value adding and value-adding hours of performance reporting were distributed. On the MP side, despite the cost area, the other areas have a similar amount of hours applied in performance reporting. However, it is worth mentioning that quality has the larger amount of non-value adding hours of performance reporting in MP. On the NDD side, despite the flexibility area, the other competitive priorities have a similar amount of effort required in hours. Almost all the hours dedicated to the flexibility area were ranked as non-value adding. To the speed area, there were no KPIs classified in the NDD side. Figure 52 and Figure 53 illustrate how performance reporting is distributed across competitive areas in both MP and NDD.

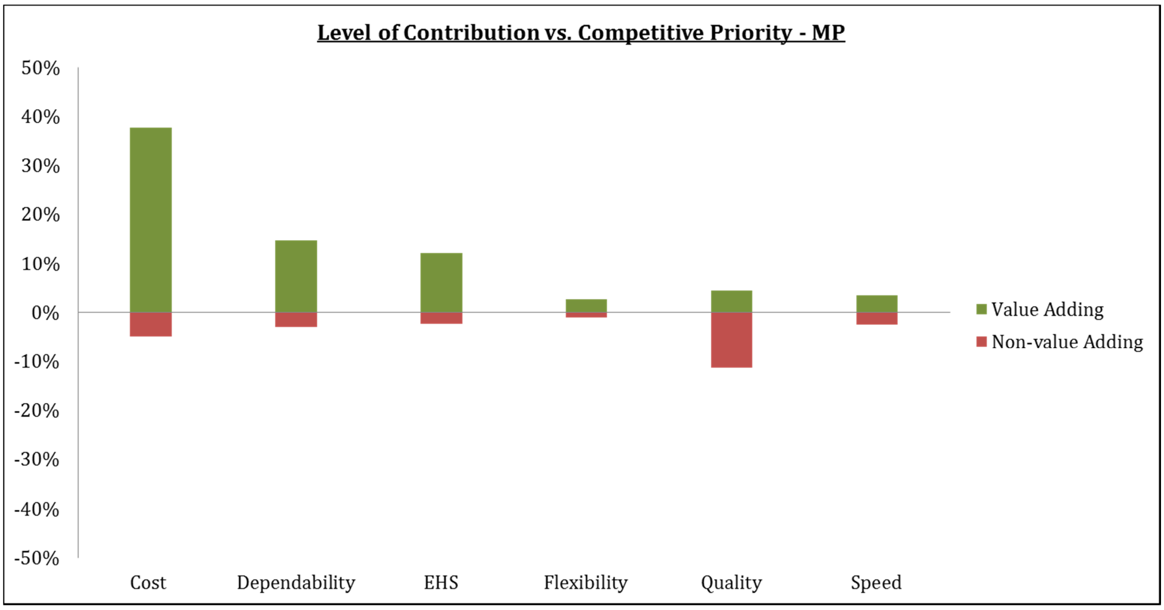


Figure 52 – Level of contribution in MP performance reporting

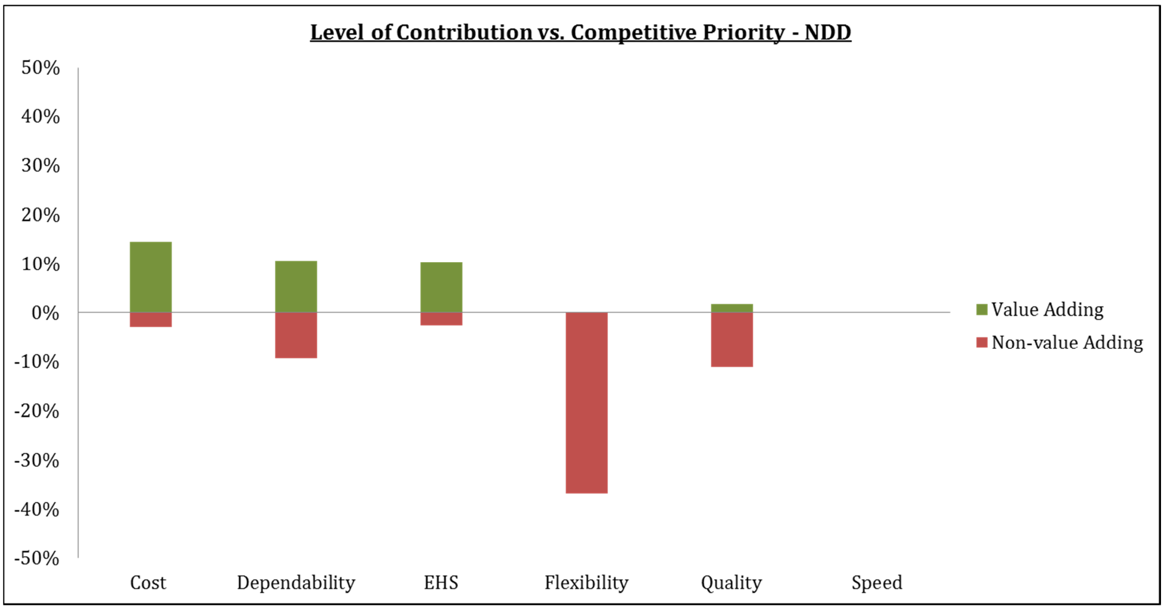


Figure 53 – Level of contribution in NDD performance reporting

There is an action plan currently under development to review supply chain performance reporting. However, due to time limitations, this research was not able to capture further action carried out in this practice by Company C.

In order to summarize and evaluate Supply Chain Performance Reporting in Case Study 3, the following points are discussed:

- **Positive aspects:** the extent in which supply chain performance reporting is undertaken by Company C is noteworthy. A number of KPIs, which cover different areas of competitive advantage, is monitored periodically by suppliers and reported to the company. It is worth mentioning that the current performance measurement system is broad;
- **Recommendations for improvement:** as the review of supply chain performance reporting was supported by the author of this thesis, recommendations follow the system adopted. First, it is recommended that a system should be created to review periodically the KPIs comprising performance reporting. Such a review should be aligned with strategic documentation, which is normally revised annually. Second, the amount of time and effort used to deliver performance reports should be considered. Typically, performance measurement systems get extensive over time, simply because new KPIs are deliberately added to them. Periodic review will ensure that only relevant KPIs are admitted into the systems. Third, the involvement of suppliers

in the review is essential. Although suppliers are external parties, they have extensive knowledge about what has been reported and to what extent information is effectively used.

6.3.2 Learning Cycle of Case Study 3

The case study in Company C assessed a set of practices for designing and improving construction supply chains. In addition, aspects concerning the conceptual framework proposed in this research were indirectly reviewed.

First, Company C has a relevant role as a major client in the UK infrastructure sector. The company is not exactly a contractor, given that construction activities are outsourced via contracts with major companies in the UK. In this context, the influence of Company C on the conceptual framework proposed in this research was evaluated correspondingly. It was found Company C has a supply chain area at the corporate level, which engages with operational procurement and different project managers. Such project managers are responsible for managing projects, in which construction activities are carried out by contractors. In this sense, Company C has a critical role in fostering and sustaining development efforts, especially in terms of supply chain design and improvement. There are interfaces between suppliers, projects, and corporate level of Company C. Such interfaces are interconnected by flows of information, materials, and capital.

Second, the contribution of Category Management, Supplier Development, Long-term Supply Chain Governance, and Early Supplier Involvement for the development of this research should be emphasized. Category Management has a commercial impact by monitoring prices in the market on a continuous basis. In addition, it is worth mentioning its relevance in including tier-2 suppliers and fostering their inter collaboration. Supplier Development comprised two significant streams. On the one hand, the development of executives in the Roads Academy has significant impact on preparing future leaders in the roads sector. On the other hand, the development of SME's establishes the opportunity to sustain supply chain improvement. Long-term Supply Chain Governance in Company C is laudable, given the inclusion of not only major contractors but also consultants, SMEs, and tier-2 suppliers. Although Early Supplier Involvement is limited by legal restrictions, Company C developed mechanisms to increase the adoption of such practice. The mechanisms include the development of innovative frameworks to contract subcontractors based on a program of activities.

Third, Prequalification of Suppliers, Supply Chain Performance Reporting, and Supply Chain Strategic Alignment constitute a set of novel practices discovered in Company C. Prequalification of suppliers in Company C comprises a 2-stage process, includes pre-market engagement, and arranges suppliers according to their performance in score-based systems. Supply Chain Performance Reporting Review is positive practice, especially because it checks the necessity of specific KPIs and reports to be provided by suppliers. Supply Chain Strategic Alignment provides a structure for aligning Company C's business strategy with its strategic suppliers. The practice demonstrated significant capability for enabling benchmarking across the supply chain.

6.4 Cross-case Analysis

The objective of cross-case analysis is to compare and cross-reference similarities and differences found across case studies. First, the conceptual framework is assessed in terms of the characteristics found in the different companies studied. Second, the practices are catalogued and summarized according to the inputs for their development.

6.4.1 Assessment of the Conceptual Framework

The main characteristics of the conceptual framework proposed were found in the companies studied, as highlighted below:

a) **Company A - Case Study 1 (Part 2):** there is a set of 26 concurrent and unique projects in the company. These projects differ in terms of scope of works, duration, location, and materials and services required. The location of the projects is widely dispersed across Brazil, and they are in the highways and mining sectors. There is a structure to manage the supply chain at the enterprise level, which is responsible for overseeing all projects. In addition, it was found that a number of teams in the project level are responsible for managing supply chain matters in the individual projects. There are 4,200 active suppliers in the supplier base, and an average number of 200 suppliers per project. There is a significant number of interactions between the enterprise level, the supplier level, and the project level. In addition, these interactions occur in three flows: information, materials and services, and capital.

b) **Company B - Case Study 2:** there is a set of concurrent and unique projects in Company B. The projects are distributed across different sectors (i.e. highways, water, nuclear) and they differ in terms of scope of works, duration, location, and materials and services required. Projects are widely distributed across the UK. A robust structure to manage the supply chain at the enterprise level is present in Company B. At this level, there are internal departments concerned with suppliers of materials and services specifically. In addition, there is an internal department concerned with supply chain strategy, performance, measurement, quality, and long-term development. The supplier base in Company B has 1,200 active suppliers, and there are 60 suppliers per project on average. Supply chain management comprises activities at the project level that should be coordinated with the corporate level. It was found that there are interactions between supplier level, project level, and enterprise level. These interactions are related to the flow of information, materials and services, and capital.

c) Company C - Case Study 3: there are numerous new projects at the moment in Company C. Suppliers carry out maintenance works in existing infrastructure assets in 12 areas. The company is not a contractor, and therefore all operational activities are outsourced to construction companies by particular contracts. The supply chain is managed from a wider perspective, and this was found to be an intrinsic governance role performed by Company C. This governance role is mainly focused on structured and long-term design and improvement efforts. There is a set of interfaces between suppliers, projects, and corporate level of Company C. The interfaces are interconnected by flows of information, materials, and capital.

Company A and Company B presents similarities and differences that should be particularly highlighted. First, the difference regarding the number of suppliers in their supplier bases is noticeable. Company A has 3 times more suppliers in the supply base, and this ratio is almost the same when the average number of suppliers per project is compared. It is clear that Company A manages its supply chain mainly by transactional relationships and limited categorization of suppliers. On the other hand, Company B has focused on reducing its number of suppliers by categorizing them in different levels.

Such categorization enabled also the development of specific strategies to be deployed in the supply chain accordingly. Second, Company A has focused on a self-delivery strategy, in which the level of outsourced activities is low. In this sense, it can also be noted the percentage of spend concentrated in materials and services, which corresponds to 75% and 25% respectively. On the other hand, Company B has chosen a high level of outsourcing, and consequently the percentage of spend in materials and services, which corresponds to 20% and 80% respectively. Finally, the inventory management strategies differ between the companies. While Company A has chosen to have inventories on site, which are coordinated by the project manager, Company B opted for just-in-time deliveries. The restricted conditions of infrastructure assets in Brazil, when compared to those found in the UK, are worth mentioning. Table 28 summarizes the characteristics found in the companies studied.

Table 28 – Characteristics found in the Case Studies

	Company A	**Company B**	**Company C**
Country	Brazil	UK	UK
Nature	Private	Private	Public
Revenue/CAPEX (per year)	£150 M (Revenue)	£900 M (Revenue)	£4 B (CAPEX)
Main Clients	Private Sector	Public Sector	-
Employees (number)	2,500	3,300	N/A
Supplier Base (number)	4,200	1,200	N/A
Tier-1 Suppliers Evaluated (number)	11	-	6
Concurrent Projects (number)	26	Not Informed	Not Informed
Suppliers per project (number)	200	60	N/A
Strategy for Delivery	Self-delivery	Outsourcing	-
% of Total Spend in Materials	75%	20%	N/A
% of Total Spend in Services	25%	80%	N/A
Strategy for Inventory	On-site	Just-in-time	N/A
Two SCM managerial levels	✓	✓	✓
Three SCM interfaces	✓	✓	✓
Three SCM types of flows	✓	✓	✓

6.4.2 Assessment of the Practices

A set of practices was appraised by cross-referencing information from the case studies. These practices add up to fifteen in total and they are summarized in Table 29.

Table 29 – Summary of Practices (second version)

Index	Practice	Interface	Type	CS 1	CS 2	CS 3
1	Supplier Relationship Management	B	I	●	○	○
2	Flexibility Management	C	D	●	○	○
3	Improvement Planning	A	I	●	○	○
4	Performance Measurement and Benchmarking	C	I	●	●	○
5	Supply Chain Risk Management	B	D	●	●	○
6	Supplier Base Management	B	D	○	●	○
7	Procurement Scheduling	A	D	○	●	○
8	Fragmentation Management	A	I	○	●	○
9	Long-term Supply Chain Governance	B	D	○	●	●
10	Early Supplier Involvement	C	D	○	●	●
11	Category Management	B	D	○	●	●
12	Supplier Development	B	I	○	●	●
13	Prequalification of Suppliers	B	I	○	○	●
14	Supply Chain Performance Reporting Review	B	I	○	○	●
15	Supply Chain Strategic Alignment	B	D	○	○	●

Key

A Indicates that the practice is positioned at **Interface A**

B Indicates that the practice is positioned at **Interface B**

C Indicates that the practice is positioned at **Interface C**

I Indicates that the practice is classified under the **Improvement Type**

D Indicates that the practice is classified under the **Design Type**

● Indicates that the practice was **assessed** in the respective Case Study (CS)

○ Indicates that the practice was **not assessed** in the respective Case Study (CS)

The characteristics of the set of practices are listed below:

- Five practices were originally captured in the literature and incorporated in the first version of the framework. The five original practices were then assessed in Case Study 1 (Part 2) in Company A;
- Two of the original practices were also assessed in Case Study 2 in Company B, along with seven additional practices found in the respective company;
- Four of the additional seven practices found in Company B were also assessed in Case Study 3 in Company C, along with three other new practices;
- Eight practices were classified under the Improvement type and seven of them under the Design type.

6.4.2.1 Supplier Relationship Management

The practice is positioned at *Interface B* and is categorized under *Improvement Type*. The positioning of the practice at this interface is justified by the existence of recurrent issues in the relationship between the Enterprise Level and the Supplier Level. These issues derive from poor integration between the aforementioned levels, especially because of the lack of trust between the organizations involved, and they affect mainly the *Information Flow*. Long-term partnerships with suppliers and the implementation of IT systems facilitating information sharing are relevant aspects in the practice.

The assessment of the practice was carried out in Company A and reported in Case Study 1 (Part 2). Table 30 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 30 – Supplier Relationship Management

Practice	Index	Item	Source
Supplier Relationship Management	1	Categorize suppliers according to the level of risk, spend, and opportunity	Case Study 1 (Part 2)
	2	Implement long-term partnerships with suppliers	Ellram and Cooper (1990)
	3	Increase information distribution and collaboration by implementing 'portals' and web-based IT systems to share information with suppliers	Ellram and Cooper (1993), Case Study 1 (Part 2)
	4	Increase early supplier involvement	Janda *et al.* (2002)
	5	Implement initiatives that fulfil the annual calendar of events (i.e. workshops, site visits, supplier day)	Case Study 1 (Part 2)
	6	Develop protocols and templates to effectively communicate with suppliers (i.e. RFPs, POs)	Case Study 1 (Part 2)
	7	Create committees to discuss long-term initiatives and partnerships regarding quality, sustainability, and social responsibility across the supply chain	Case Study 1 (Part 2)

The aim of Supplier Relationship Management is to structure, increase, and sustain the integration between the Enterprise Level and Supplier Level over time. It is the understanding of this research that integration is a key aspect to be achieved in ETO construction supply chains, especially because of the fragmented nature found in these supply chain structures. A key enabler of integration is the development of long-term relationships.

6.4.2.2 Flexibility Management

The practice is positioned at *Interface C* and is categorized under *Design Type*. The positioning of the practice at this interface is attributed to its capacity in solving responsiveness problems between the Project Level and the Supplier Level. These difficulties originate from the poor identification and categorization of uncertainties, and typically result in operational problems affecting the *Physical Flow*. In practice, the need to consider flexibility at the design stage is emphasized to create strategies for sharing risks, and to integrate the decision-making process.

The assessment of the practice was carried out in Company A and reported in Case Study 1 (Part 2). Table 31 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 31 – Flexibility Management

Practice	Index	Item	Source
Flexibility Management	1	Identify and categorize uncertainties	Whitten *et al.* (2012), Gosling *et al.* (2013a), Case Study 1 (Part 2)
	2	Increase the level of real-time information shared with the supply chain	Lee (2004), Whitten *et al.* (2012)
	3	Design flexible products and facilitate production postponement	Lee (2004), Whitten *et al.* (2012), Gosling *et al.* (2013a)
	4	Identify new supply bases and markets constantly	Whitten *et al.* (2012)
	5	Implement inventory buffers	Case Study 1 (Part 2)
	6	Prepare for relocation of capacity and outsourcing	Case Study 1 (Part 2)
	7	Centralize the evaluation of uncertainties at the Enterprise Level	Case Study 1 (Part 2)

The aim of Flexibility Management is to identify, categorize, and respond to uncertainties affecting responsiveness between the Project Level and the Supplier Level over time. It is the understanding of this research that flexibility management enables high responsiveness to predictable and unpredictable events (i.e. supply disruptions). More than allocate inventory buffers, the task of managing flexibility comprises the constant analysis of supply bases and markets.

6.4.2.3 Improvement Planning

The practice is positioned at *Interface A* and is categorized under *Improvement Type*. The positioning of the practice at this interface is justified by its capability in organizing actions to eliminate problems between the Enterprise Level and the Project Level. It was perceived that contractors have difficulties in implementing improvement efforts with project teams in order to solve supply chain problems. These issues directly affect the *Information Flow* between the aforementioned levels. The need for procedures and standards, and the identification of performance gaps in the supply chain are key elements in Improvement Planning.

The assessment of the practice was carried out in Company A and reported in Case Study 1 (Part 2). Table 32 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 32 – Improvement Planning

Practice	Index	Item	Source
Improvement Planning	1	Increase the level of commitment towards improvement in the supply chain	McGinnis and Vallopra (2001)
	2	Reduce formality concerning supplier involvement	McGinnis and Vallopra (2001)
	3	Implement improvement tools in partnership with suppliers	Corbett *et al.* (1999), Foggin *et al.* (2004), Drysdale (2013)
	4	Increase benchmarking to capture best practices from suppliers	Luu *et al.* (2008)
	5	Integrate multiple departments to deploy supply chain improvement	Case Study 1 (Part 2)
	6	Identify, categorize, and cross-reference supplier gaps with existing operational problems prior to devising action plans	Case Study 1 (Part 2)
	7	Implement, audit, and train the teams in procedures for capturing non-conformances in quality and cost deviations generated by the supply chain	Case Study 1 (Part 2)
	8	Implement improvement plans from the perspective of the Enterprise Level	Case Study 1 (Part 2)

The aim of Improvement Planning is to systematize improvement efforts in ETO construction supply chains. It is the understanding of this research that planning is needed in order to implement relevant action plans and prioritize efforts. Prioritization is a key issue to be addressed, especially when resources for improvement are scarce.

6.4.2.4 Performance Measurement and Benchmarking

The practice is positioned at *Interface C* and is categorized under *Improvement Type*. The positioning of the practice at this interface is attributed to the recurrent problems found in metrics (i.e. poor measurement) and lack of references (i.e. limited interaction and benchmarking). These issues affect the *Information Flow* between the Supplier Level and Project Level.

The assessment of the practice was carried out in Company A and Company B and respectively reported in Case Study 1 (Part 2) and Case Study 2. Table 33 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 33 – Performance Measurement and Benchmarking

Practice	Index	Item	Source
Performance Measurement and Benchmarking	1	Implement qualitative and quantitative metrics	Beamon (1999)
	2	Balance and align metrics according to the competitive priorities	Hayes and Wheelwright (1979b), Case Study 1 (Part 2), Case Study 2
	3	Consider multiple competitive dimensions when implementing performance measurement	Melnyk *et al.* (2010), Estampe *et al.* (2013), Case Study 1 (Part 2), Case Study 2
	4	Consider the context in which metrics will be developed	Childerhouse *et al.* (2003)
	5	Cascade performance measurement across different organization and supply chain levels	Garcia *et al.* (2012)
	6	Enable benchmarking where possible	Garcia *et al.* (2012), Case Study 1 (Part 2), Case Study 2
	7	Assess variability of performance measures over time	Case Study 1 (Part 2)
	8	Review the performance measurement system	Case Study 1 (Part 2), Case Study 2
	9	Implement templates, preferentially web-based, for capturing inputs for performance measurement	Case Study 1 (Part 2), Case Study 2
	10	Consider performance measurement in decision-making	Case Study 1 (Part 2)
	11	Attribute different weights to the metrics according to their relevance and revise the weights periodically	Case Study 2

The aim of Performance Measurement and Benchmarking is to apply metrics that can be used to facilitate benchmarking. It is the understanding of this research that decision-making in supply chain management should be based on KPIs.

6.4.2.5 Supply Chain Risk Management

The practice is positioned at *Interface B* and is categorized under *Design Type*. The allocation of the practice at this interface is explained by the level of engagement required between the Enterprise Level and the Supplier Level to deal with risks, which might produce effects on the *Information Flow* and on the *Capital Flow*.

The assessment of the practice was carried out in Company A and Company B and respectively reported in Case Study 1 (Part 2) and Case Study 2. Table 34 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 34 – Supply Chain Risk Management

Practice	Index	Item	Source
Supply Chain Risk Management	1	Consider a wide typology of risks	Grimsey and Lewis (2002), Zsidisin and Smith (2005), Case Study 1 (Part 2), Case Study 2
	2	Consider in the risk assessment not only tier-1 suppliers, but also relevant tier-2, tier-3, and suppliers in other tiers if applicable	New (2010), HMG (2013)
	3	List and categorize supply chain risks	Gosling *et al.* (2013b), Simchi-Levi *et al.* (2014), Case Study 1 (Part 2)
	4	Cross-reference risks with sources of uncertainties	Gosling *et al.* (2013b)
	5	Calculate the time to recover from disruptions (especially those related to unpredictable events)	Simchi-Levi *et al.* (2014)
	6	Allocate buffers where applicable (i.e. inventory)	Azambuja and O'Brien (2009)
	7	Use third-party firms to conduct financial risk assessments	Case Study 2
	8	Monitor the obsolescence of materials	Holweg and Pil (2001)
	9	Implement and audit protocols for risk management (i.e. site visits, financial assessments, list of risky materials/suppliers, review of annual spend)	Case Study 1 (Part 2), Case Study 2
	10	Devise comprehensive contingency plans	Case Study 2
	11	Consider a cross-functional approach to implement risk management at the Enterprise Level and Project Level	Case Study 1 (Part 2), Case Study 2

The aim of Supply Chain Risk Management is to address uncertainties and devise solutions that mitigate or eliminate risks. It is the understanding of this research that there are different types of risks.

6.4.2.6 Supplier Base Management

The practice is positioned at *Interface B* and is categorized under *Design Type*. The positioning of the practice at this interface is justified by the level of influence of the Enterprise Level in defining policies and guidelines to manage the Supplier Level. These definitions generate effects on both the *Information Flow* and the *Capital Flow*. The size and nature of supplier bases influence supply chain management. A small supplier base is pointed out as a requisite for developing long-term relationships with suppliers according to Sarkar and Mohapatra (2006). Cousins (1999) points out that initiatives regarding supplier base have multiple implications, and therefore decisions in this area should be focused on a long-term view. It is the opinion of this author that a cost-benefit analysis should be taken into consideration when promoting changes in the supply base.

The assessment of the practice was carried out in Company B, and the practice was reported in Case Study 2. Table 35 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 35 – Supplier Base Management

Practice	Index	Item	Source
Supplier Base Management	1	Reduce the supplier base and review it systematically	Sarkar and Mohapatra (2006), Case Study 2
	2	Consider a long-term supply chain strategy	Cousins (1999)
	3	Establish long-standing partnerships with suppliers	Sarkar and Mohapatra (2006)
	4	Categorize the supply base in different levels according to relevant criteria (i.e. risk, spend, opportunity), and review it frequently	Gosling *et al.* (2010), Gosling *et al.* (2013a), Case Study 2
	5	Contemplate the different needs of the Enterprise Level and the Project Level (i.e. temporary suppliers)	Case Study 2
	6	Implement a 'Supply Chain Radar' to continuously identify new suppliers in the market in a structured way	Case Study 2

The aim of Supplier Base Management is to streamline the supply base. It is the understanding of this research that the Supplier Level is composed of different categories of suppliers, which should be based on relevant criteria. These criteria should be reviewed periodically and they consider that temporary relationships with suppliers should occur only when demanded by projects.

6.4.2.7 Procurement Scheduling

The practice is positioned at *Interface A* and is categorized under *Design Type*. The insertion of the practice at this interface is attributed to the way the Enterprise Level and the Project Level interact when planning procurement, which affects the *Information Flow*. Lin and Shaw (1998) argue that due to the large number of suppliers in supply chains, the synchronization of activities should comprise suppliers and assemblers. In this context, procurement planning plays a crucial role for procuring the work packages in alignment with the project's schedule. According to Rimmer (2009), contractors tend to concentrate the division of work into work packages. The decision regarding the allocation of work packages and the facilitated exchange of information with suppliers (i.e. RFPs, POs) depends on the type of relationship. Dowlatshahi (1998) affirms that when suppliers meet qualitative criteria and when long-term relationships are established, early purchasing and supplier involvement strategies should be implemented in order to reduce complications in procurement scheduling.

The assessment of the practice was carried out in Company B, and the practice was reported in Case Study 2. Table 36 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 36 – Procurement Scheduling

Practice	Index	Item	Source
Procurement Scheduling	1	Promote high integration between the Enterprise and the Project levels (i.e. regular meetings)	Case Study 2
	2	Enable early participation of procurement in projects' definitions (i.e. since bidding stage)	Dowlatshahi (1998), Case Study 2
	3	Consolidate and categorize the work packages	Rimmer (2009), Case Study 2
	4	Synchronize production, procurement, and supply chain activities in terms of planning and execution	Lin and Shaw (1998), Case Study 2
	5	Use IT systems to consolidate data and make it available	Case Study 2
	6	Categorize, monitor, and quantify reworks and waiting (i.e. design issues, changes of scope)	Case Study 2

The aim of Procurement Scheduling is to synchronize activities and reduce waste in the procurement process. It is the understanding of this research that the Enterprise Level has a central role in fostering integration with project sites and ensuring that materials and services will be provided on time, cost, and quality.

6.4.2.8 Fragmentation Management

The practice is positioned at *Interface A* and is categorized under *Improvement Type*. The allocation of the practice at this interface is explained by the lack of integration and consequent high fragmentation in the *Information Flow*. Dainty *et al.* (2001) pointed out a set of possible solutions to enable supply chain integration including the following elements: increase trust, early supplier involvement, less reliance on contracts, increase training, and educate people in the benefits of collaborating, among others. Stevens (1989) proposed a set of stages to achieve supply chain integration: full supply chain visibility, integrated planning, focus on tactical rather than strategic issues, extensive use of electronic data interchange, and responding to customer demand. By analysing the potential implications of the elements and stages aforementioned, one can notice the impact they might have both at the Enterprise Level and at the Project Level.

The assessment of the practice was carried out in Company B, and the practice was reported in Case Study 2. Table 37 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 37 – Fragmentation Management

Practice	Index	Item	Source
Fragmentation Management	1	Clarify the roles and responsibilities and integrate supply chain management at the Enterprise Level and Project Level	Case Study 2
	2	Increase trust and early supplier involvement	Dainty *et al.* (2001)
	3	Support and educate the project team to make decisions and share information	Dainty *et al.* (2001), Case Study 2
	4	Share relevant information regarding suppliers' past performance to support decision making	Stevens (1989), Case Study 2
	5	Focus on tactical rather than strategic issues	Stevens (1989)
	6	Organize committees and forums regularly to integrate the Enterprise Level and the Project Level	Case Study 2

The aim of Fragmentation Management is to integrate the Enterprise Level and the Project Level to facilitate decision-making. It is the understanding of this research that in many cases projects operate in isolation from each other and from the Enterprise Level. In addition, given the high number of suppliers and specific demands from each project, situations in which the Enterprise Level fails to reduce fragmentation are frequent.

6.4.2.9 Long-term Supply Chain Governance

The practice is positioned at *Interface B* and is categorized under *Design Type*. The practice is positioned at this interface because the Enterprise Level needs to establish clear policies, guidelines, and procedures to streamline the *Information Flow* and the *Capital Flow*. In order to properly establish governance in supply chains, Richey *et al.* (2010) indicate that companies involved must be open to being aligned, communicative, joint structured, assessed in supply chain metrics, and open to interdependence. Following the same line, Saad *et al.* (2002) indicate two central points related to governance in construction supply chains: continuous and shared learning, and strong commitment from key partners.

The assessment of the practice was carried out in Company B and Company C and respectively reported in Case Study 2 and Case Study 3. Table 38 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 38 – Long-term Supply Chain Governance

Practice	Index	Item	Source
Long-term Supply Chain Governance	1	Adopt a long-term strategy and establish long-term partnerships with the supply chain	Saad *et al.* (2002), Case Study 2, Case Study 3
	2	Reduce financial co-dependence of suppliers	Case Study 2
	3	Match your product, processes, production strategies, and supply chain structure	Case Study 2
	4	Eliminate managerial barriers between the Enterprise Level and the Project Level	Richey *et al.* (2010), Case Study 2
	5	Learn from different industries, enable benchmarking where possible, and create templates to capture and share best practices	Case Study 2, Case Study 3
	6	Increase integration and collaboration with suppliers, including important tier-2 and SMEs, by using electronic means	Saad *et al.* (2002), Richey *et al.* (2010), Case Study 2, Case Study 3
	7	Promote cross-functional integration with different departments at the Enterprise Level	Case Study 2
	8	Use small projects as grounds for training and experimenting	Case Study 2
	9	Do not focus on price-driven decisions	Case Study 3

The aim of Long-term Supply Chain Governance is to propose policies and guidelines to sustain development. It is the understanding of this research that the governance role should not be influenced by price-driven considerations.

6.4.2.10 Early Supplier Involvement

The practice is positioned at *Interface C* and is categorized under *Design Type*. The practice is positioned at this interface due to benefits derived from increased contact between the Supplier Level and the Project Level, which improves the *Information Flow* and the *Physical Flow.* Early Supplier Involvement (ESI) has been acknowledged as a useful technique for managing construction supply chains. Such a technique has been alternatively named as pre-construction and has been widely discussed in the literature (Dowlatshahi 1998; McIvor 2004). ESI reduces conflicts, uncertainty, and variability, and increases customer satisfaction. In addition, ESI requires a specific policy to manage the level of supplier involvement, which should be aligned with top-level business guidelines. McIvor (2004) indicates that ESI be pushed and supported by senior management. In addition, this author recommends that all parties involved in ESI define the risks, behaviours, and attitudes necessary to support collaboration.

The assessment of the practice was carried out in Company B and Company C and respectively reported in Case Study 2 and Case Study 3. Table 39 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 39 – Early Supplier Involvement

Practice	Index	Item	Source
Early Supplier Involvement	1	Enable early supplier involvement where possible	McIvor (2004), Dowlatshahi (1998), Case Study 2, Case Study 3
	2	Use BIM models to increase alignment and share information with the supply chain	McIvor (2004), Case Study 2
	3	Implement a template to capture achievements generated by early supplier involvement	Case Study 2
	4	Reduce last-minute changes that affect early definitions	Case Study 2
	5	Use senior management to implement and support ESI	McIvor (2004)
	6	Define criteria to support the Enterprise Level and Project Level in selecting suppliers to be involved early	Case Study 2
	7	Increase pipeline visibility (12 months minimum) by adopting collaborative frameworks in complex programmes	Case Study 3

The aim of Early Supplier Involvement is to increase collaboration in construction supply chains. It is the understanding of this research that pipeline visibility is a key enabler of this practice.

6.4.2.11 Category Management

The practice is positioned at *Interface B* and is categorized under *Design Type*. The allocation of the practice at this interface is explained by the need to rationalize the way categories of materials and services in the Supplier Level will be managed by the Enterprise Level. The practice affects the *Information Flow* and the *Capital Flow*. Vollmann and Cordon (2000) pointed out the use of categories as a strategic decision that enables analysis and decision-making regarding a set of similar materials or services. Another relevant point to be considered is supply chain visibility, which is included by Foggin *et al.* (2004) in the proposition of a supply chain diagnostic tool.

The assessment of the practice was carried out in Company B and Company C and respectively reported in Case Study 2 and Case Study 3. Table 40 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 40 – Category Management

Practice	Index	Item	Source
Category Management	1	Create categories of suppliers based on relevant criteria (i.e. risk, spend, opportunity)	Case Study 2
	2	Consolidate, cross-reference, and make available all information regarding category management in web-based IT systems in order to enable decision-making	Vollmann and Cordon (2000), Case Study 2, Case Study 3
	3	Review the categories periodically	Case Study 2
	4	Allocate expert personnel to manage categories	Case Study 2
	5	Explore synergies across different business units when managing categories	Case Study 2, Case Study 3
	6	Implement a standard range of performance measures to assess and compare the performance of categories	Case Study 2
	7	Create templates and committees to capture best practice across categories	Case Study 2, Case Study 3
	8	Monitor prices in the market	Case Study 3
	9	Implement category management also in strategic tier-2 suppliers, and increase supply chain visibility	Foggin *et al.* (2004), Case Study 3
	10	Incorporate inputs from risk assessment in category management, and devise contingency plans	Case Study 2

The aim of Category Management is to manage the supply chain by categories. It is the understanding of this research that the creation and implementation of categories should be tracked and assessed by specific performance measures.

6.4.2.12 Supplier Development

The practice is positioned at *Interface B* and is categorized under *Improvement Type*. The positioning of the practice at this interface is justified by the role of the Enterprise Level in ensuring that the Supplier Level meet current and future capabilities as required. The practice has influence on the *Information Flow* and the *Capital Flow*. Handfield *et al.* (2000) defined supplier development as the efforts carried out by a buyer to improve the performance or capability of suppliers to meet current or future supply needs. These authors also reinforce the view that the adoption of this practice requires a two-way commitment and the implementation of effective means to measure performance.

The assessment of the practice was carried out in Company B and Company C and respectively reported in Case Study 2 and Case Study 3. Table 41 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 41 – Supplier Development

Practice	Index	Item	Source
Supplier Development	1	Devise specific strategies to support the development, performance, and capabilities of SMEs	Handfield *et al.* (2000), Case Study 2, Case Study 3
	2	Define specific criteria for selecting suppliers that will participate in the development process	Case Study 2
	3	Create a brochure explaining the development scheme	Case Study 2
	4	Engage with universities and educational institutions to prepare and supplement training	Case Study 2, Case Study 3
	5	Use internal people from multiple departments to deliver training sessions according to their expertise	Case Study 2, Case Study 3
	6	Assess training quality and learning continuously	Case Study 2
	7	Increase the offering of e-learning platforms	Case Study 2
	8	Combine training modules with consulting	Case Study 2
	9	Develop executives and future leaders in the sector	Case Study 3
	10	Capture/share information from SMEs in a systemic way	Case Study 2
	11	Establish clear targets for performance measures to assess the contribution of suppliers' development	Handfield *et al.* (2000), Case Study 2, Case Study 3

The aim of Supplier Development is to devise and implement strategies that ensure suppliers have the competences required. It is the understanding of this research that supplier development initiatives should be customized to attend the needs of different stakeholders (i.e. training and consulting for SMEs).

6.4.2.13 Prequalification of Suppliers

The practice is positioned at *Interface B* and is categorized under *Improvement Type*. The allocation of the practice at this interface is supported by the need to select suppliers effectively, which has implications on the *Information Flow* and on the *Capital Flow*. According to de Boer *et al.* (2001), there are different methods supporting supplier selection, and the authors pointed out that the problem of selecting suppliers should comprise different phases, which includes prequalification. Prequalification of suppliers must be based on criteria measured in a scoring system, and such criteria should be ranked according to their relevance (de Boer *et al.* 2001; Sarkar and Mohapatra 2006).

The assessment of the practice was carried out in Company C, and the practice was reported in Case Study 3. Table 42 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 42 – Prequalification of Suppliers

Practice	Index	Item	Source
Prequalification of Suppliers	1	Devise a multiple stage process for selecting suppliers	de Boer *et al.* (2001), Sarkar and Mohapatra (2006), Case Study 3
	2	Implement a supplier radar and pre-market engagement	Case Study 3
	3	Consider inputs from risk assessment in prequalification of suppliers	Case Study 3
	4	Adopt external auditors for selecting critical suppliers	Case Study 3
	5	Use web-based IT systems to compile and share information regarding suppliers	Case Study 3
	6	Devise multiple criteria to be considered in prequalification	de Boer *et al.* (2001), Sarkar and Mohapatra (2006), Case Study 3
	7	Develop prequalification of supplier at the Enterprise Level	Case Study 3
	8	Consult data of suppliers in third-party databases	Case Study 3
	9	Review the prequalification process systematically to comply with up-to-date regulations	Case Study 3

The aim of Prequalification of Suppliers is to support the supplier selection in construction supply chains. It is the understanding of this research that stages prior to supplier selection have to focus on the implementation of strategic tools and techniques. Such approaches comprise supplier radars, and pre-market engagement, among others.

6.4.2.14 Supply Chain Performance Reporting Review

The practice is positioned at *Interface B* and is categorized under *Improvement Type*. The positioning of the practice at this interface is justified by the constant need for feedback from the Supplier Level to the Enterprise Level. It was learned in this research that supply chain performance reporting could become expansive, expensive, and resource intensive. These issues typically derive from the lack of review of performance measurement systems over time. Neely *et al.* (1995) indicate that performance measurement structures should be periodically re-evaluated in order to consider changes in the business environment. In addition, Beamon (1999) maintains that large and complex performance measurement systems make effective measurement difficult. The problems derived from excessive and poorly reviewed performance measurement systems affect the *Information Flow*.

The assessment of the practice was carried out in Company C, and the practice was reported in Case Study 3. Table 43 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 43 – Supply Chain Performance Reporting Review

Practice	Index	Item	Source
Supply Chain Performance Reporting Review	1	Devise a comprehensive and balanced set of metrics	Hayes and Wheelwright (1979b), Case Study 3
	2	Review metrics periodically	Neely *et al.* (1995), Case Study 3
	3	Align metrics with strategic objectives	Case Study 3
	4	Simplify performance measurement and balance the effort for calculating the reporting of them	Beamon (1999), Case Study 3
	5	Involve suppliers in the creation and review of metrics	Garcia *et al.* (2012), Case Study 3
	6	Do not tailor metrics for particular projects regularly	Case Study 3

The aim of Supply Chain Performance Reporting Review is to ensure effectiveness and balance in performance measurement. It is the understanding of this research that supply chain performance should be assessed systematically, especially when there are multiple, unique, and concurrent projects within the same enterprise. In order to comply with the constant changes in the business environment, it is necessary to devise metrics and review them constantly against the strategic objectives of the business. In addition, suppliers should be consulted when devising and reviewing metrics.

6.4.2.15 Supply Chain Strategic Alignment

The practice is positioned at *Interface B* and is categorized under *Design Type*. The allocation of the practice at this interface is explained by the need of alignment between the Enterprise Level and the Supplier Level. According to Lee (2004), supply chain alignment aims at the creation of incentives to achieve better performance. In addition, this author indicates the following as pre-requisites for alignment: free exchange of information, clear definition of responsibilities, and equal distribution of risks, costs, and gains in improvement initiatives. Handfield *et al.* (2000) pointed out that supply chain strategy should be aligned with the overall business strategy in order to gain competitive advantage. Supply chain alignment impacts the *Information Flow*.

The assessment of the practice was carried out in Company C, and the practice was reported in Case Study 3. Table 44 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 44 – Supply Chain Strategic Alignment

Practice	Index	Item	Source
Supply Chain Strategic Alignment	1	Rank suppliers according to the level of alignment	Case Study 3
	2	Carry out strategic alignment only for strategic suppliers	Case Study 3
	3	Use strategic alignment to increase competitive advantage, provide feedback, and enable benchmarking	Handfield *et al.* (2000), Case Study 3
	4	Use external assessors to support the alignment process and increase its credibility	Case Study 3
	5	Define a cycle for the strategic alignment	Case Study 3
	6	Attribute weights to different areas in the strategic alignment tool	Case Study 3
	7	Define a basic list of tools, techniques, and practices to be assessed in suppliers (i.e. template or checklist to guide the evaluation)	Case Study 3
	8	Establish clear targets to be achieved by suppliers in the assessment process	Case Study 3
	9	Exchange best practices between strategic suppliers	Lee (2004), Case Study 3

The aim of Supply Chain Strategic Alignment is to foster and sustain the alignment between the key parties in a supply chain. It is the understanding of this research that alignment is an enabler for long-term partnerships.

6.4.3 Learning Cycle of Cross-case Analysis

The findings of the studies related to the practices were summarized in individual tables (Table 30 to Table 44). These tables contain the key inputs provided by the studies, and they are explicitly indicated. After the practices were compiled, findings from the literature were additionally provided - where applicable - to support the background of the new set of practices proposed in the framework. Figure 54 illustrates the second version of the framework in the light of the findings of cross-case analysis.

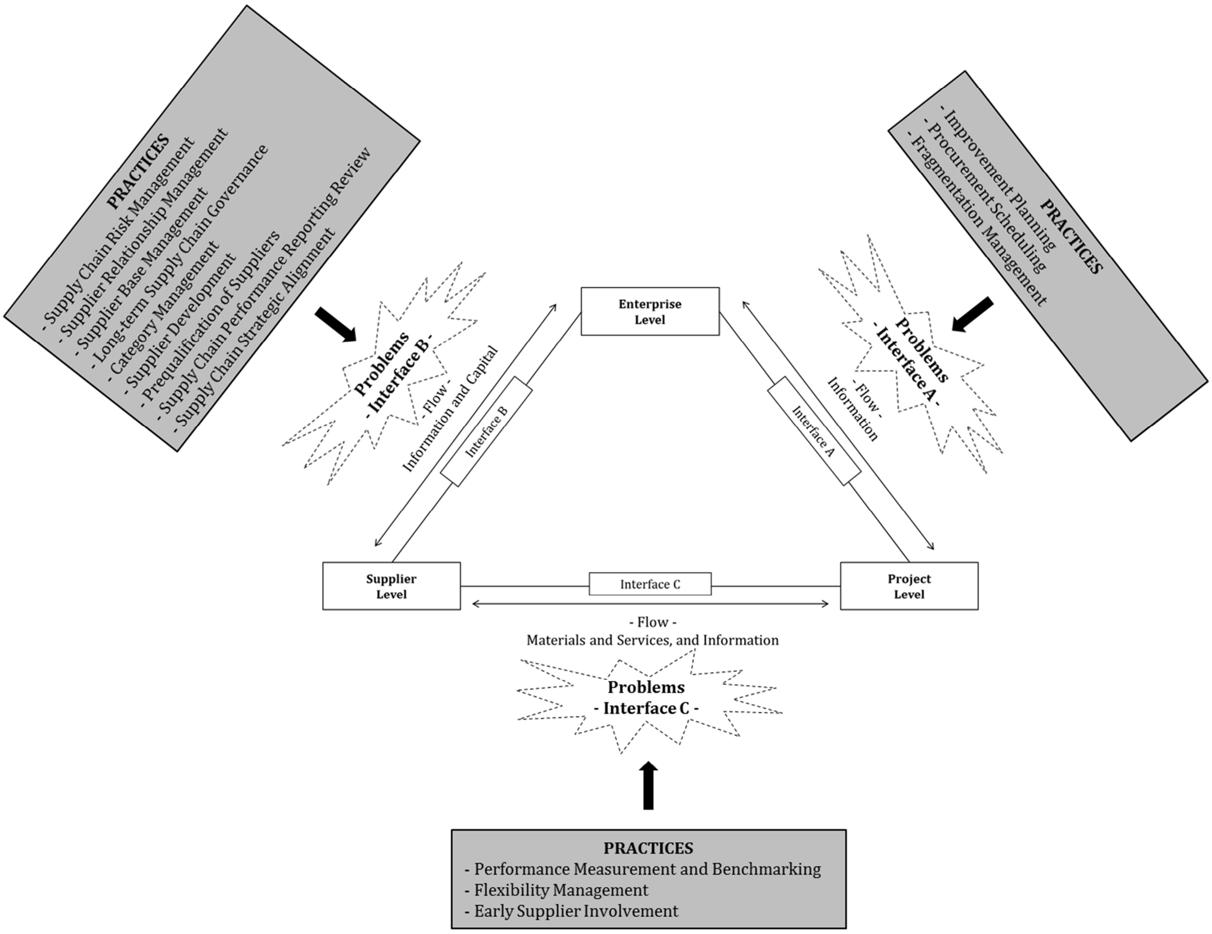


Figure 54 – Overview of the Framework (second version)

By cross analysing the case studies, it was possible to identify the overlaps and individual contributions of each case to the development of the proposed framework. First, the conceptual view of construction supply chains is assessed in the view of the findings of the cases. This view contributed to a revising and validating of its overall structure. Second, the set of practices was reviewed and expanded according to the findings of case studies. It is worth mentioning that cross-case analysis enabled a moment of reflection. The reflection comprised the 'big-picture' of the conceptual framework and its evolution over the research process. It was also possible to link the contributions of each case to the recommendations on 'how' each of the practices should be carried out. The similarities and differences between the case studies were reviewed in-depth. In addition, the companies studied were also contrasted in order to verify how their intrinsic characteristics are comparable.

7 EVALUATING THE FRAMEWORK

The evaluation of the solution is presented in this chapter as illustrated in Figure 55. The second version of the framework is presented to a focus group composed of practitioners and academics. The views of the group were captured and summarized in a set of recommendations, which were later used to support the final refinement process of the framework. Each recommendation of the focus group was carefully considered in the final version and the actions taken are detailed throughout the chapter.

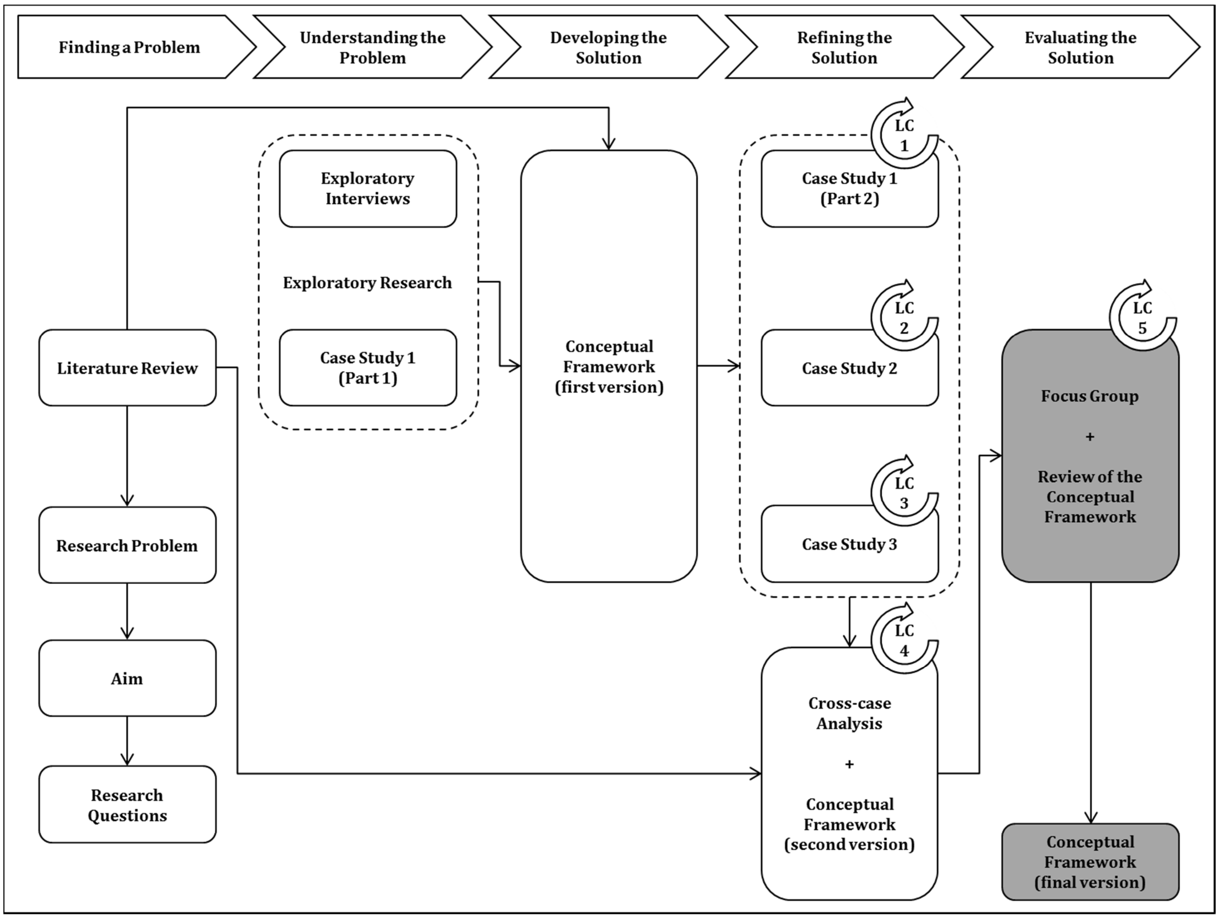


Figure 55 – Activities and developments in the 'Evaluating the Solution' stage

7.1 Focus Group – Report

Participants were formally invited to take part in the focus group by e-mail, which also included relevant information regarding its purpose and general guidelines. The participants were selected according to their level of expertise in the area, practical experience, and availability. Due to travel restrictions, only participants from Company B and Company C were able to attend the event, which took place in the UK. A supplier of Company C, which was previously involved in the research process, also designated a representative to attend the focus group. It is worth mentioning that participants have different positions in their organizations, and the discussion included academics from University A. The supervisor of this thesis was also present in the focus group session. Table 45 summarizes the information regarding the participants and Table 46 illustrates the agenda of the focus group.

Table 45 – List of participants in the focus group

Participant	Position of the Participant	Company/University
1	Senior Lean Practitioner	Company C
2	Lean Six-Sigma Technical Leader for Supply Chain Deployment	Company C
3	Performance Assurance Manager	Company C (Supplier)
4	Supply Chain Manager	Company C
5	Head of Supply Chain Management	Company C
6	Senior Quantity Surveyor	Company B
7	PhD Candidate	University A
8	Professor	University A

Table 46 – Agenda of the focus group

Agenda	
09:30 – 10:00	Arrival and Refreshments
10:00 – 10:15	Welcome, Introductions, and Instructions
10:15 – 11:00	Presentation – Conceptualization of Construction Supply Chains Discussion – 1st round of questions
11:00 – 11:10	Break
11:10 – 12:15	Presentation – Practices for Designing and Improving Construction Supply Chains Discussion – 2nd round of questions
12:15 – 12:30	Final Remarks

In order to guide the discussion, a set of key questions was prepared in advance. The questions were devised so that the conceptual framework and practices proposed in this research were effectively evaluated.

The current version of the conceptual framework (section 6.4) was presented to the participants following the above-mentioned agenda. The purpose of the presentation was to organize and display the contents of the discussion in a didactic fashion. The interaction between participants was fostered during the discussion. In general, the level of participation was equal between the eight participants. The entire focus group session was recorded, as previously informed in the invitation e-mail, for future reference.

7.1.1 Conceptualization of Construction Supply Chains

First, the conceptualization of construction supply chains was presented to the participants. The presentation was delivered so that the development and proposition of all elements of the conceptualization were clearly justified. Next, a discussion with the participants was centred in three questions:

a) **In what context is the conceptual framework applicable?**
b) **What are the strengths and weaknesses of the conceptual framework as presented?**
c) **To what extent is the conceptualization of construction supply chains real?**

The general contents of the conceptualization were acknowledged as existing in practice by all participants. The different levels, flows, and interfaces were reported as a reality when compared to current supply chain activities, which is illustrated as follows:

"I can certainly see the flows... I am thinking about my supply chain... and all the levels".

When the discussion focused on the differences between the Enterprise Level and the Project Level, the participants agreed that those differences are intrinsic to construction, as highlighted:

"certain things are better done centrally and others are better done by project".

However, it was agreed among participants how projects perform differently. Regarding the Enterprise Level, it was stated:

> *"you see great variation in the performance of projects within the same enterprise".*

Participants attributed such variations in performance to the limited understanding of the environment in construction supply chains. It was found during the discussion that there is a clear need for a framework in the field of construction supply chains, especially because of the short-term managerial mind-set found across the sector. One of the participants highlighted the following:

> *"when you talked about the limited and short-term nature of commitment… with the triangle (conceptual framework), you are suggesting a longer-term".*

This interpretation emphasizes that a long-term strategic viewpoint is perceived in the conceptualization proposed in this research. As previously discussed, temporary and local supply chain relationships will continuously exist due to specific requirements and restrictions of projects. However, these relationships should be managed accordingly, especially when the governance role and the supplier base structures are implemented.

In the focus group, different supply chain issues were discussed based on the proposed conceptualization. Interestingly, when the conceptualization was displayed on the big screen, participants used it as a means to debate as a group the problems according to the flows and interfaces displayed. One of the key purposes of the conceptualization is to be used as background for identifying, locating, and addressing supply chain problems effectively.

When examining the overall ideas of the framework, participants indicated concerns in the field of long-term governance. Clearly, the heavy construction sector lacks strategy, alignment, and commitment across its supply chains, as one can note from the quotes below:

> *"you need to have strategic partners that you have a relationship at the strategic level... these suppliers work across multiple projects, programs… and they have a stronger link with the enterprise level".*

"we've got a bigger program in a large investment portfolio and we are trying to do stuff... to incentivise more commitment across projects ... and the fact we are trying to do that recognizes that it probably doesn't exist".

As described above, participants acknowledge in their own words the need for a structural basis for managing construction supply chains. On the other hand, they transmit the idea that such a basis is not tangible and available in their companies yet.

Two central recommendations were formulated during the focus groups as a contribution to improve the proposed conceptualization:

- To consider the role of the owner, and external factors (i.e. changes in the markets, contractual agreements, among others) in the proposed conceptualization;
- To position the practices at the respective interfaces and flows in the conceptualization of construction supply chains.

7.1.2 Practices for Designing and Improving Construction Supply Chains

First, the set of practices for designing and improving construction supply chains was presented to the participants. The presentation was delivered so that the set of practices was introduced in terms of the potential impacts of the practices in designing and improving construction supply chains. Next, a discussion with the participants was centred on the following question:

a) Are the practices proposed for designing and improving construction supply chains achievable?

The overall impression regarding the set of practices presented was positive. Participants indicated that the practices might have significant implications in the 'real world'. In terms of implementation, the discussion indicated the need for comprehensive governance roles to be achieved by contractors towards their supply chains in order to promote change. This idea was summarized by one of the participants as following:

"it is easier for us as clients to push things out".

Following the discussion, it was pointed out that sometimes suppliers are not ready to implement or collaborate in efforts regarding supply chain design and improvement. Major concerns were focused on SMEs, as highlighted below:

> *"because one of the big things we see is a barrier for SMEs trying to do business with us… all the testing and checking… we want less… and in some cases to go directly to tender…"*

A significant share of suppliers in construction supply chains are SMEs. However, these companies typically lack management expertise. It was pointed out by participants that the adoption of practices should consider the context of SMEs and that any changes should contribute to simplifying supply chain management rather than complicating it.

In the same context, the discussion was then shifted to the extent construction supply chains are currently managed. It was acknowledged in the focus group that the management activities generally reach only tier-1 suppliers, as stated by one of the participants:

> *"it is interesting, because in our world we are engaged with tier-1 suppliers… and they should apply practices in their supply chains"*

This myopic view of construction supply chains certainly has side effects, as also pointed out by one of the participants:

> *"we've got a great disparity between tier-1 and tier-2 performance".*

As suppliers in a supply chain are evaluated, especially in tier-1 and tier 2, it was mentioned by participants that their performance decreases across the multiple supply chain tiers. It was discussed and reinforced by the group that there is a need to implement practices that reach at least tier-2 suppliers in order to achieve significant changes in the overall supply chain performance.

Recommendations suggested by the focus group regarding the set of practices proposed are summarized as follows:

- To position the practices at the respective interfaces and flows in the conceptualization of construction supply chains;

- To streamline the set of practices by checking the overlaps between them;
- To present the overall aim of each practice after they are streamlined.

7.1.3 Learning Cycle of Focus Group

The focus group was chosen as a strategy to evaluate the framework developed in this research because the activity is focused on gathering insights from a guided discussion. The framework, comprised of a conceptualization of construction supply chains and a set of practices, was presented to a group of practitioners and academics from the UK. Following the presentation, the discussion offered significant insights for the evaluation and validation of the ideas contained in the framework. The group of participants collaborated in the discussion actively, exposing their ideas and pointing out specific areas of the framework to be enhanced. The atmosphere in which the focus group was conducted was positive. Although direct and indirect commercial relationships exist between the participants, these commercial matters did not affect the development of the activity. Moreover, attendance of the confirmed participants was 100%.

In terms of lessons learned and inputs to improve the framework, the focus group reached its purpose in gathering constructive contributions. First, participants indicated that the conceptualization of construction supply chains needs to consider the effect of direct external parties (i.e. owners, designers), and indirect influences of the market (i.e. price fluctuations, unpredicted disruptions in supplies). Second, it was the opinion of participants that the practices should be positioned at the interfaces and flows in order to provide a visual idea of their setting in the framework. Third, the observation of overlaps between the practices was suggested, so that they can be streamlined and consequently reduced in number.

7.2 Final View of the Framework

The final version of the framework is formulated under the light of the recommendations of the focus group. Recommendations were analysed and summarized in Table 47, along with the actions taken regarding each of them.

Table 47 – Recommendations of the focus group and corresponding actions

Index	Recommendation	Action
1	To streamline the set of practices by checking the similarities and overlaps between them	The contents of each of the 15 practices were carefully analysed. The overlaps and similarities were identified, and some of the practices were merged
2	To present the overall aim of each practice after they are streamlined	As some of the practices were merged, the overall aims were reviewed where applicable
3	To consider the role of the owner and external factors (i.e. changes in the markets, contractual agreements, among others) in the proposed conceptualization	In the final version, new information was added to the framework in order to provide a more realistic view of ETO construction supply chains
4	To position the practices at the respective interfaces and flows in the conceptualization of construction supply chains	The practices were positioned at the interfaces and flows as suggested. A key was created and added to the final version to facilitate the understanding of the framework

7.2.1 Review of the Practices

According to *Recommendation 1* of Table 47, the contents of the fifteen practices presented within section 6.4.2 were fully reviewed as shown in Figure 56. It is worth mentioning that, after the reviewing process, the contents of the practices presented in sections 6.4.2.11, 6.4.2.12, 6.4.2.13, and 6.4.2.15, continue as originally displayed.

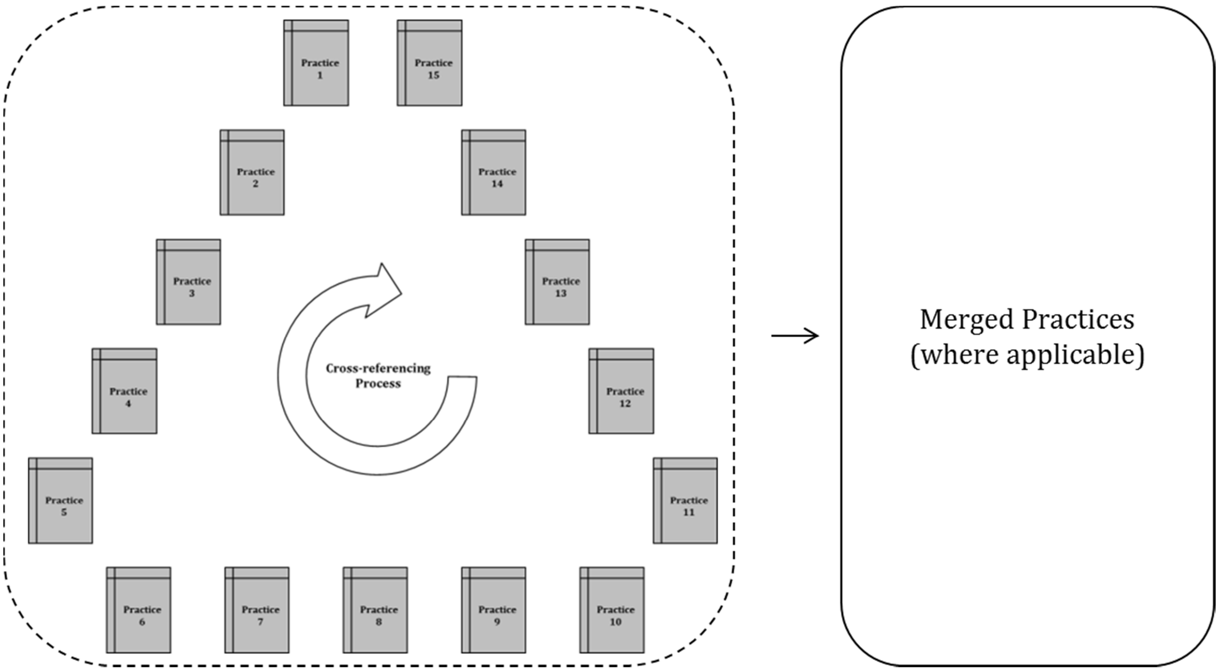


Figure 56 – Review of the Practices

Similarities and overlaps were found in the eleven remaining practices and they were merged. According to *Recommendation 2* of Table 47, the merged practices received new names and their overall aims were revised accordingly.

- The practices presented in sections 6.4.2.1, 6.4.2.6, and 6.4.2.9 were merged into a new practice, called Supply Chain Governance (presented in section 7.2.1.1);
- The practices presented in sections 6.4.2.2 and 6.4.2.5 were merged into a new practice, called Supply Chain Flexibility and Risk Management (presented in section 7.2.1.2);
- The practices presented in sections 6.4.2.3, 6.4.2.4, and 6.4.2.14 were merged into a new practice, called Performance Management (presented in section 7.2.1.3);
- The practices presented in sections 6.4.2.7, 6.4.2.8, and 6.4.2.10 were merged into a new practice, called Early Supply Chain Involvement (presented in section 7.2.1.4).

Table 48 presents the summary of the final version of the practices.

Table 48 – Summary of Practices (final version)

Index	Practice	Interface	Type	CS 1	CS 2	CS 3
1	Supply Chain Governance	B	D, I	●	●	●
2	Supply Chain Flexibility and Risk Management	B, C	D	●	●	○
3	Performance Management	A, B, C	I	●	●	●
4	Early Supply Chain Involvement	A, C	D, I	○	●	●
5	Category Management	B	D	○	●	●
6	Supplier Development	B	I	○	●	●
7	Prequalification of Suppliers	B	I	○	○	●
8	Supply Chain Strategic Alignment	B	D	○	○	●

Key

A Indicates that the practice is positioned at **Interface A**

B Indicates that the practice is positioned at **Interface B**

C Indicates that the practice is positioned at **Interface C**

I Indicates that the practice is classified under the **Improvement Type**

D Indicates that the practice is classified under the **Design Type**

● Indicates that the practice was **assessed** in the respective Case Study (CS)

○ Indicates that the practice was **not assessed** in the respective Case Study (CS)

7.2.1.1 Supply Chain Governance

The practice is generated from the review of similarities and overlaps of Supplier Relationship Management (6.4.2.1), Supplier Base Management (6.4.2.6), and Long-term Supply Chain Governance (6.4.2.9). By reviewing the contents, the following overlaps were found in specific items, and the way in which they were merged is explained as follows:

- Item 1 of Supplier Relationship Management and Item 4 of Supplier Base Management were merged → Item 6 in Table 49;
- Item 2 of Supplier Relationship Management, Items 2 and 3 of Supplier Base Management, and Item 1 of Long-term Supply Chain Governance were merged → Item 9 in Table 49;
- Item 3 of Supplier Relationship Management and Item 6 of Long-term Supply Chain Governance were merged → Item 14 in Table 49.

The remaining items were extracted from the original proposition of the three aforementioned practices. The practice is positioned at *Interface B* and is categorized under the *Design Type* and the *Improvement Type*. This definition was based on the focus of governance, which is mainly concerned with the long-standing interactions between the Enterprise Level and the Supplier Level. It should be mentioned that this practice is focused on the *Information Flow* and on the *Capital Flow*.

The aim of Supply Chain Governance is to establish policies and guidelines that structure long-term development of ETO construction supply chains over time. It is the understanding of this research that the governance role should not be influenced by price-driven decisions. In addition, specific criteria should be used to categorize suppliers and provide basis for managing the supplier base. Furthermore, it is the view of this study that long-term partnerships are a key variable to be implemented and sustained.

The assessment of the practice was carried out in Company A, Company B, and Company C, and respectively reported in Case Study 1 (Part 2), Case Study 2, and Case Study 3. Table 49 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 49 – Supply Chain Governance

Practice	Index	Item	Source
Supply Chain Governance	1	Increase early supplier involvement	Janda *et al.* (2002)
	2	Implement initiatives that fulfil the annual calendar of events (i.e. workshops, site visits, supplier day)	Case Study 1 (Part 2)
	3	Develop protocols and templates to effectively communicate with suppliers (i.e. RFPs, POs)	Case Study 1 (Part 2)
	4	Create committees to discuss long-term initiatives and partnerships regarding quality, sustainability, and social responsibility across the supply chain	Case Study 1 (Part 2)
	5	Reduce the supplier base and review it systematically	Sarkar and Mohapatra (2006), Case Study 2
	6	Categorize the supply base in different levels according to relevant criteria (i.e. risk, spend, opportunity), and review it frequently	Gosling *et al.* (2010), Gosling *et al.* (2013a), Case Study 1 (Part 2), Case Study 2
	7	Contemplate the different needs of the Enterprise Level and the Project Level (i.e. temporary suppliers)	Case Study 2
	8	Implement a 'Supply Chain Radar' to continuously identify new suppliers in the market in a structured way	Case Study 2
	9	Adopt a long-term strategy and establish long-term partnerships with the supply chain	Ellram and Cooper (1990), Cousins (1999), Saad *et al.* (2002), Sarkar and Mohapatra (2006), Case Study 2, Case Study 3
	10	Reduce financial co-dependence of suppliers	Case Study 2
	11	Match products, processes, production strategies, and supply chain structures	Case Study 2
	12	Eliminate managerial barriers between the Enterprise Level and the Project Level	Richey *et al.* (2010), Case Study 2
	13	Learn from different industries, enable benchmarking, and create templates to capture and share best practices	Case Study 2, Case Study 3
	14	Increase integration and collaboration with suppliers, including important tier-2 and SMEs, by implementing 'portals' and web-based IT systems to share information with suppliers	Ellram and Cooper (1993), Saad *et al.* (2002), Richey *et al.* (2010), Case Study 1 (Part 2), Case Study 2, Case Study 3
	15	Promote cross-functional integration with different departments at the Enterprise Level	Case Study 2
	16	Use small projects as grounds for training and experimenting	Case Study 2
	17	Do not focus on price-driven decisions	Case Study 3

7.2.1.2 Supply Chain Flexibility and Risk Management

The practice is generated from the review of similarities and overlaps of Flexibility Management (6.4.2.2) and Supply Chain Risk Management (6.4.2.5). By reviewing the contents, the following overlaps were found in specific items, and the way in which they were merged is explained as follows:

- Item 5 of Flexibility Management and Item 6 of Supply Chain Risk Management were merged → Item 10 in Table 50;
- Item 6 of Flexibility Management and Item 10 of Supply Chain Risk Management were merged → Item 11 in Table 50.

The remaining items were extracted from the original proposition of the two aforementioned practices. The practice is positioned at *Interface B* and *Interface C* and is categorized under the *Design Type*. This definition was based on the focus of risk management, which is mainly concerned with the inherent risks between the Supplier Level and the Project Level. It should be mentioned that this practice is focused on the *Information Flow, on the Physical Flow*, and on the *Capital Flow*.

The aim of Supply Chain Flexibility and Risk Management is to identify uncertainties, anticipate the risks linked to them, and devise plans to effectively eliminate or mitigate their impacts. It is the understanding of this research that such impacts occur between the Supplier Level and the Project Level, which certainly produce implications in operational activities. A key risk to be avoided is supply disruption, which produces multiple problems, including delays in project delivery and cost overruns. The task of tackling risks and increasing responsiveness should comprise not only predictable events, but also those incidents that could not be directly predictable. Thus, commensurate contingency plans should be devised and people should be trained in them as a means to achieving excellence in risk management.

The assessment of the practice was carried out in Company A, Company B, and respectively reported in Case Study 1 (Part 2) and Case Study 2. Table 50 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 50 – Supply Chain Flexibility and Risk Management

Practice	Index	Item	Source
Supply Chain Flexibility and Risk Management	1	Centralize the evaluation of uncertainties at the Enterprise Level	Case Study 1 (Part 2)
	2	Identify and categorize uncertainties	Whitten *et al.* (2012), Gosling *et al.* (2013a), Case Study 1 (Part 2)
	3	Consider in the risk assessment not only tier-1 suppliers, but also relevant tier-2, tier-3, and suppliers in other tiers if applicable in the light of the uncertainties categorized	New (2010), HMG (2013), Whitten *et al.* (2012), Gosling *et al.* (2013a)
	4	Consider a wide typology of risks	Grimsey and Lewis (2002), Zsidisin and Smith (2005), Case Study 1 (Part 2), Case Study 2
	5	List and categorize supply chain risks	Gosling *et al.* (2013b), Simchi-Levi *et al.* (2014), Case Study 1 (Part 2)
	6	Cross-reference risks with sources of uncertainties	Gosling *et al.* (2013b)
	7	Increase the level of real-time information shared with the supply chain	Lee (2004), Whitten *et al.* (2012)
	8	Design flexible products and facilitate production postponement	Lee (2004), Whitten *et al.* (2012), Gosling *et al.* (2013a)
	9	Identify new supply bases and markets constantly	Whitten *et al.* (2012)
	10	Implement inventory buffers	Azambuja and O'Brien (2009), Case Study 1 (Part 2)
	11	Devise comprehensive contingency plans, including relocation of capacity and outsourcing	Case Study 1 (Part 2), Case Study 2
	12	Calculate the time to recover from disruptions (especially those related to unpredictable events)	Simchi-Levi *et al.* (2014)
	13	Use third-party firms to conduct financial risk assessments	Case Study 2
	14	Monitor the obsolescence of materials	Holweg and Pil (2001)
	15	Implement and audit protocols for risk management (i.e. site visits, financial assessments, list of risky materials/suppliers, review of annual spend)	Case Study 1 (Part 2), , Case Study 2
	16	Consider a cross-functional approach to implement risk management at the Enterprise Level and Project Level	Case Study 1 (Part 2), Case Study 2

7.2.1.3 Performance Management

The practice is generated from the review of similarities and overlaps of Improvement Planning (6.4.2.3), Performance Measurement and Benchmarking (6.4.2.4), and Supply Chain Performance Reporting Review (6.4.2.14). By reviewing the contents, the following overlaps were found in specific items, and the way in which they were merged is explained as follows:

- Item 8 of Improvement Planning and Item 10 of Performance Measurement and Benchmarking were merged → Item 5 in Table 51;
- Items 2, 3 and 8 of Performance Measurement and Benchmarking and Items 1, 2, and 3 of Supply Chain Performance reporting Review were merged → Item 7 Table 51;
- Items 1 and 5 of Improvement Planning, Item 5 of Performance Measurement and Benchmarking, and Item 5 of Supply Chain Performance Reporting Review were merged → Item 9 in Table 51;
- Item 4 of Improvement Planning and Item 6 of Performance Measurement and Benchmarking were merged → Item 10 in Table 51.

The remaining items were extracted from the original proposition of the three aforementioned practices. The practice is positioned at *Interface A*, *Interface B*, and *Interface C*, and is categorized under the *Improvement Type*. This definition was based on the need to assess supply chain performance at the Supplier Level and the Project Level. It is worth mentioning that this practice is focused on the *Information Flow*.

The aim of Performance Management is to devise supply chain measures and guide the improvement process. It is the understanding of this research that the decision-making process in ETO construction supply chains should be based on appropriate performance measures.

The assessment of the practice was carried out in Company A, Company B, and respectively reported in Case Study 1 (Part 2) and Case Study 2. Table 51 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 51 – Performance Management

Practice	Index	Item	Source
Performance Management	1	Reduce formality concerning supplier involvement	McGinnis and Vallopra (2001)
	2	Implement improvement tools in partnership with suppliers	Corbett *et al.* (1999), Foggin *et al.* (2004), Drysdale (2013)
	3	Identify, categorize, and cross-reference supplier gaps with existing operational problems prior to devising action plans	Case Study 1 (Part 2)
	4	Implement, audit, and train the teams in procedures for capturing non-conformances in quality and cost deviations generated by supply chain	Case Study 1 (Part 2)
	5	Implement improvement plans from the perspective of the Enterprise Level and consider performance of the supply chain in decision-making	Case Study 1 (Part 2)
	6	Implement qualitative and quantitative metrics	Beamon (1999)
	7	Consider multiple competitive dimensions when implementing performance measurement, balance and align metrics according to such dimensions, and review the dimensions and metrics on a periodic basis	Hayes and Wheelwright (1979b), Neely *et al.* (1995), Melnyk *et al.* (2010), Estampe *et al.* (2013), Case Study 1 (Part 2), Case Study 2, Case Study 3
	8	Consider the context in which metrics will be developed	Childerhouse *et al.* (2003)
	9	Cascade improvement efforts across different organizational and supply chain levels	McGinnis and Vallopra (2001), Garcia *et al.* (2012), Case Study 1 (Part 2), Case Study 3
	10	Enable benchmarking where possible	Luu *et al.* (2008), Garcia *et al.* (2012), Case Study 1 (Part 2), Case Study 2
	11	Assess variability of performance measures over time	Case Study 1 (Part 2)
	12	Implement templates, preferentially web-based, for capturing inputs for performance measurement	Case Study 1 (Part 2), Case Study 2
	13	Simplify performance measurement and balance the effort for calculating reporting them	Beamon (1999), Case Study 3
	14	Do not tailor metrics for particular projects regularly	Case Study 3
	15	Attribute different weights to the metrics according to their relevance and revise the weights periodically	Case Study 2

7.2.1.4 Early Supply Chain Involvement

The practice is generated from the review of similarities and overlaps of Procurement Scheduling (6.4.2.7), Fragmentation Management (6.4.2.8), and Early Supplier Involvement (6.4.2.10). By reviewing the contents, the following overlaps were found in specific items, and the way in which they were merged is explained as follows:

- Item 1 of Procurement Scheduling, Item 1 of Fragmentation Management, and Item 6 of Early Supplier Involvement were merged → Item 1 in Table 52;
- Item 2 of Procurement Scheduling, Item 2 of Fragmentation Management, and Item 1 of Early Supplier Involvement were merged → Item 2 in Table 52;
- Item 5 of Procurement Scheduling and Item 7 of Early Supplier Involvement were merged → Item 5 in Table 52;
- Item 6 of Procurement Scheduling and Item 4 of Early Supplier Involvement were merged → Item 6 in Table 52.

The remaining items were extracted from the original proposition of the three aforementioned practices. The practice is positioned at *Interface A* and *Interface C*, and is categorized under the *Design Type* and *Improvement Type*. This definition was based on the need to structure the way in which the supply chain is involved early. It is worth mentioning that this practice is focused on the *Information Flow* and on the *Physical Flow*.

The aim of Early Supply Chain Involvement is to synchronize the planning activities between the Supplier Level, the Project Level, and the Enterprise Level in order to facilitate decision-making. It is the understanding of this research that increased pipeline visibility, achieved by the adoption of collaborative frameworks, is a key variable for achieving early collaboration of the supply chain.

The assessment of the practice was carried out in Company B and Company C, and respectively reported in Case Study 2 and Case Study 3. Table 52 summarizes the practice, how to conduct it, and the sources supporting its proposition in this research.

Table 52 – Early Supply Chain Involvement

Practice	Index	Item	Source
Early Supply Chain Involvement	1	Define clear roles when integrating the Enterprise Level and Project Level to promote early supplier involvement	Case Study 2
	2	Increase trust and participation of the supply chain in pre-construction activities	McIvor (2004), Dowlatshahi (1998), Dainty *et al.* (2001), Case Study 2, Case Study 3
	3	Consolidate and categorize the work packages	Rimmer (2009), Case Study 2
	4	Synchronize production, procurement, and supply chain activities in terms of planning and execution	Lin and Shaw (1998), Case Study 2
	5	Increase pipeline visibility (12 months minimum) by adopting collaborative frameworks in complex programmes, and use IT systems to consolidate and share data	Case Study 2, Case Study 3
	6	Categorize, monitor, and quantify reworks and waiting (i.e. design issues, changes of scope) that affect early supplier involvement	Case Study 2
	7	Support and educate the project team to make decisions and share information	Dainty *et al.* (2001), Case Study 2
	8	Share relevant information regarding suppliers' past performance to support decision making	Stevens (1989), Case Study 2
	9	Focus on tactical rather than strategic issues	Stevens (1989)
	10	Organize committees and forums regularly to integrate the Enterprise Level and the Project Level	Case Study 2
	11	Use BIM models to increase alignment and share information with the supply chain	McIvor (2004), Case Study 2
	12	Implement a template to capture achievements generated by early supplier involvement	Case Study 2
	13	Use senior management to implement and support ESI	McIvor (2004)

7.2.2 Review of the Conceptualization

According to *Recommendation 3* of Table 47, the role of the owner and external factors (i.e. changes in the markets, contractual agreements, among others) are now incorporated in the proposed conceptualization. The Owner is now connected to the Enterprise Level, in order to provide a more comprehensive view of ETO construction supply chains. However, due to time limitations in the development of the research process, the new interface between the Owner and the Enterprise Level is not studied in detail. Figure 57 provides a view of the link of the owner in the conceptual view of construction supply chains.

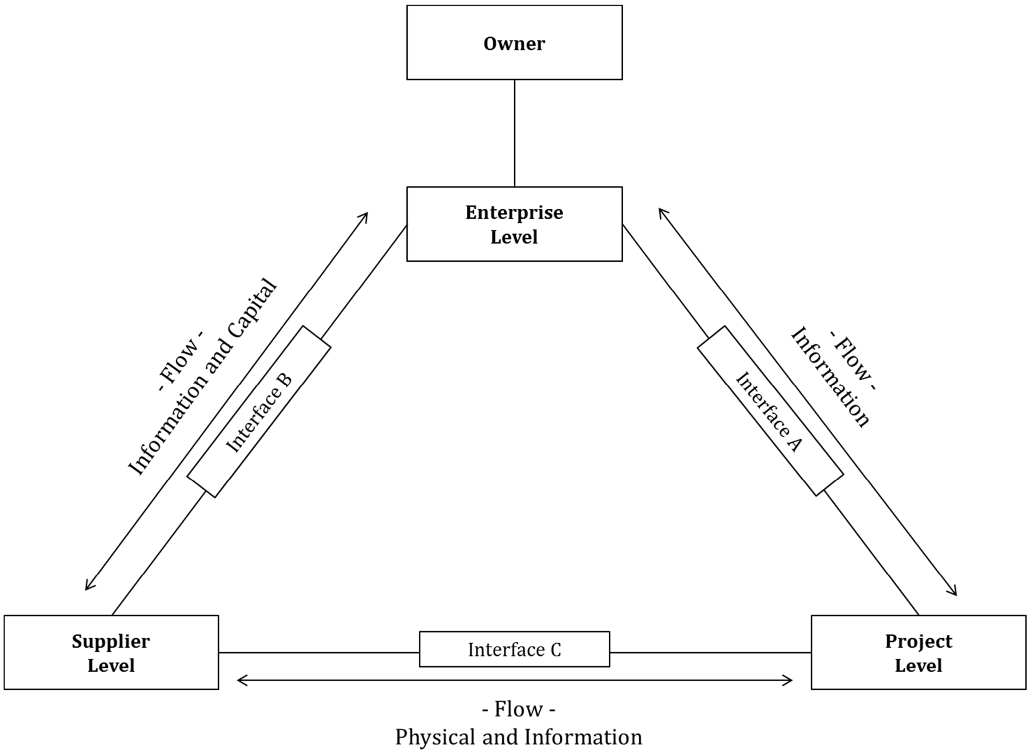


Figure 57 – The Owner in the conceptual view of construction supply chains

According to *Recommendation 4*, the practices were positioned at the interfaces and flows as suggested. As illustrated in Table 48, eight indexed practices are presented in the final version of the framework. A key was created and added to the final version to facilitate the understanding of the framework. The practices are distributed across the interfaces and types of flows as follows:

- Two practices are positioned at Interface A, both of them related to the Information flow as presented in Figure 58;

		FLOWS		
INDEX	PRACTICES	Information	Capital	Physical
3	Performance Management	✓		
4	Early Supply Chain Involvement	✓		

Figure 58 – Practices in Interface A

- Seven practices are positioned at Interface B. All of them are related to the Information Flow and five of them to the Capital Flow, as presented in Figure 59;

		FLOWS		
INDEX	PRACTICES	Information	Capital	Physical
1	Supply Chain Governance	✓	✓	
2	Supply Chain Flexibility and Risk Management	✓	✓	
3	Performance Management	✓		
5	Category Management	✓	✓	
6	Supplier Development	✓	✓	
7	Prequalification of Suppliers	✓	✓	
8	Supply Chain Strategic Alignment	✓		

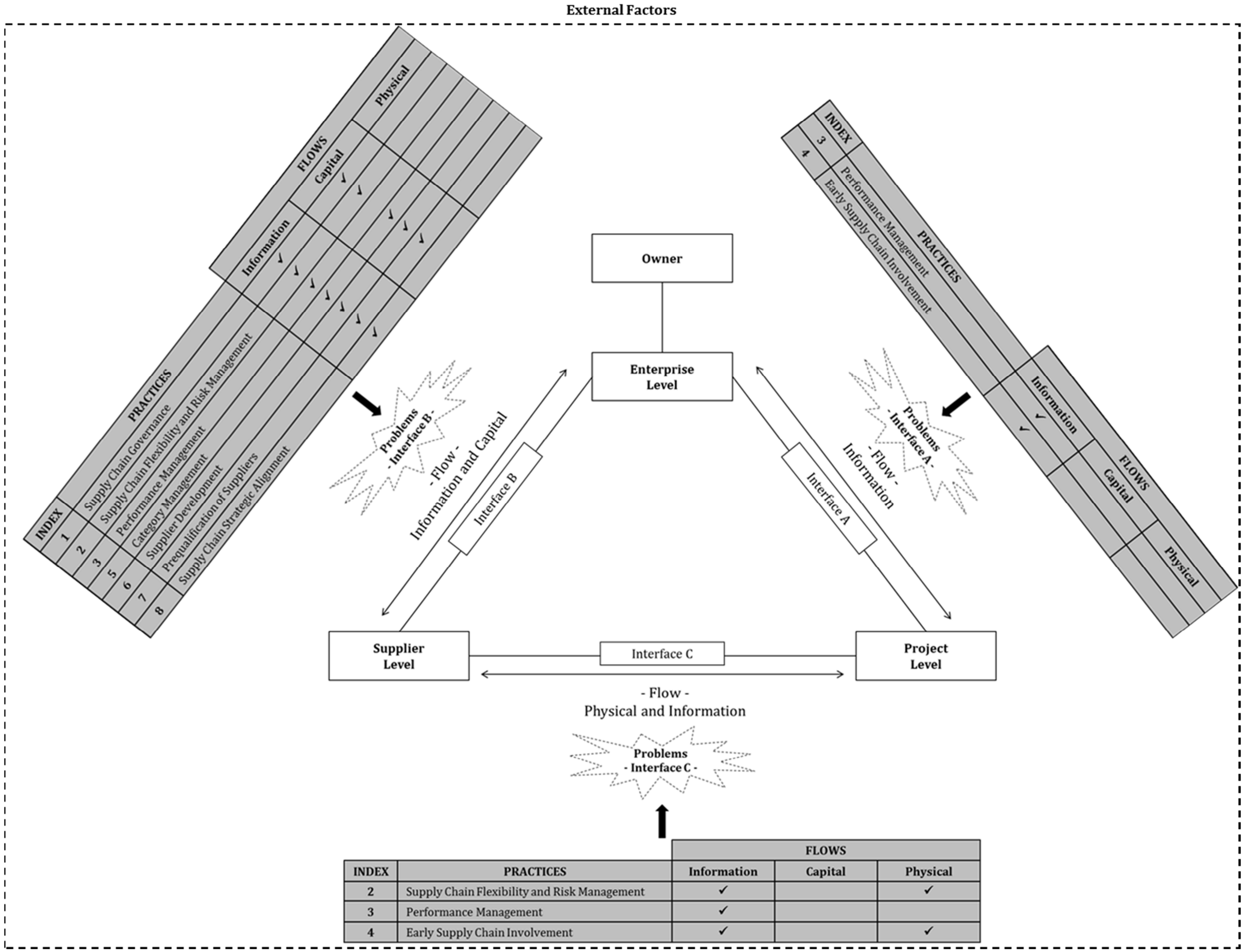
Figure 59 – Practices in Interface B

- Three practices are positioned at Interface C. All of them are related to the Information Flow and two of them at the Physical Flow, as show in Figure 60.

		FLOWS		
INDEX	PRACTICES	Information	Capital	Physical
2	Supply Chain Flexibility and Risk Management	✓		✓
3	Performance Management	✓		
4	Early Supply Chain Involvement	✓		✓

Figure 60 – Practices in Interface C

All recommendations provided by the focus group were incorporated in the review of the practices and of the conceptualization. Finally, Figure 61 illustrates the overview of the final version of the framework.



INDEX	PRACTICES	FLOWS Information	Capital	Physical
2	Supply Chain Flexibility and Risk Management	✓		✓
3	Performance Management	✓		
4	Early Supply Chain Involvement	✓		✓

Figure 61 – Overview of the Framework (final version)

8 CONCLUSION

Construction supply chains are problematic. There are recurring problems affecting these supply chains in terms of quality, delivery, and cost, among others. These problems influence the execution of construction projects, and ultimately they impact the overall performance of the enterprise. In this chapter, a review of the aim and research questions demonstrates how they were addressed. Next, the central contributions of this research are presented. Finally, the limitations are outlined and recommendations for future research are provided.

8.1 A Review of the Aim and Research Questions

The aim, as defined for this research, is to develop a conceptual framework and best practices to tackle the problems of construction supply chains. In order to realize this aim, a solution was developed through design science research. The solution is divided into two parts, a conceptual framework and best practices for designing and improving construction supply chains. The development of the solution was based on findings from the literature and from exploratory research. Next, this solution was refined in three case studies in organizations in the heavy construction sector. Finally, the solution was evaluated in a focus group.

The research questions initially proposed in this research are now reviewed. Following each question, a brief answer is provided in order to demonstrate how they were addressed as the research process evolved.

a) **How should construction supply chains be conceptualized in a framework?** The conceptual view of construction supply chains is proposed in terms of the parties involved and how they are arranged in levels, how these parties interact throughout the life cycle of projects, the flows encapsulating these interactions, and the interfaces connecting the levels proposed. Three central types of parties exist in construction supply chains, namely the suppliers, the projects, and the business level of a construction company. Although projects and the business level belong to the same organization, they are treated separately due to the intrinsic nature observed in construction companies. The respective parties are grouped in the Enterprise Level, the Project Level, and the Supplier Level. The numerous interactions between the parties within the levels are categorized in three types of flows, namely the Information Flow, the Physical Flow, and the Capital Flow. In order to organize the conceptual view, three interfaces are proposed to position the levels and the flows. Interface A links the Enterprise Level and the Project Level, and the predominant flow at this interface is the Information Flow. Interface B links the Enterprise Level and the Supplier Level, and the most relevant flows are the Information Flow and the Capital Flow. Interface C links the Supplier Level and the Project Level, and the major flows at this interface are the Information Flow and the Physical Flow.

b) **How can the problems of construction supply chains be located?** By having the conceptual view of construction supply chains as a background, the problems in this environment can be categorized and located. First, problems are categorized in terms of how they affect the flows (i.e. information, physical, and capital) and their consequent impacts on performance (i.e. delivery performance, cost overruns). Second, the aforementioned interfaces can be used to locate the problems precisely. By cross-referencing the categories of problems according to the flows, their impacts in performance, and the interfaces, the task of creating action plans is facilitated. For example, in order to tackle problems at Interface B, specific people at the Enterprise Level and at the Supplier Level should be involved in the development of action plans. Thus, the action plans can be based on a map of problems, which are effectively situated at specific interfaces and flows involving the right people. In this sense, after the problems are categorized and located, it is easier to achieve assertive solutions.

c) **How can practices be selected, assessed, cross-referenced, and consolidated in a framework?** Practices are related to long-term development in this research. As stated above, practices are not a 'one-time-thing' and they are not 'one-size-fits-all'. Therefore, they should be developed based on a particular context. This research has considered the context of ETO construction supply chains in the heavy infrastructure sector. Moreover, the perspective for the development and the adoption of the practices is the one concerning the focal company of such supply chains, namely the contractor. Initially, a set of five practices were selected from the literature and connected to the interfaces proposed at the early stages (first version) of the framework. As the case studies evolved, new practices were assessed and described in the respective reports. The practices were then cross-referenced, given that some of them were assessed in more than one case study. Furthermore, additional findings in the literature were reviewed to provide support to the propositions of the practices (where applicable). Thus, an iterative process concerning the extraction of practices in the cases, the cross-case analysis of the contents of each practice, and the introduction of findings from the literature is proposed. Such a process enables the consolidation of the set of fifteen practices presented in the second version of the framework.

d) **How can a set of practices be adopted by construction companies for tackling supply chain problems?** The development of the set of practices was focused on their practical application. The practices can be cascaded across the Enterprise Level, the Supplier Level, and the Project Level. In addition, the development of the set of practices was based on the extraction of real experiences and views of existing companies in ETO construction supply chains. Such a realistic view, combined with the theoretical background in the literature, produces a robust framework to be analysed, adapted, and adopted by construction companies. The final version of the framework contains eight practices, and each of them comprises specific items that explain *how* practitioners in a construction company should consider the implementation of the respective practice.

8.2 Contribution

Research developments related to supply chain management have mainly focused on operation and control. In this sense, studies in the field of logistics and its functions (i.e. inventory management, routing optimization, materials handling) were prioritized in early research agendas. In addition, such advances were primarily developed for make-to-stock supply chains. In the mid-1990s, research approaching the topic of supply chain management has shifted from an operational perspective to a more tactical and strategic perspective. In this context, process-based frameworks were introduced in order to manage supply chains. Examples of such frameworks are Supply Chain Operation Reference (SCOR) and Global Supply Chain Forum (GSCF) models. Again, such frameworks were primarily conceived for make-to-stock supply chain structures. However, the increasing market competition has produced an encouraging environment for investigating contextualized frameworks for managing other supply chain structures.

Early developments in the 1990s introduced new concepts and production philosophies in the construction sector, which contributed to consolidating lean construction. Research regarding supply chain management in construction was developed more recently, especially from 2000 onwards. Such research focused mainly on activities on site, in which logistics functions such as materials handling and layout optimization were adapted from manufacturing and adopted in construction. Later, research has evolved into more strategic discussions, in which the focus has shifted from a project perspective to a business perspective.

Construction, especially in the heavy infrastructure sector, requires a contextualized approach for managing its supply chains. However, such an approach must encompass a long-term view, and therefore incorporate perspectives both from the project and the business levels. In addition, the design and improvement of construction supply chains, which have been overlooked by construction companies over time, should also be incorporated in the contextualized proposition.

A contribution of this study is the conceptualization of construction supply chains, which provides an understanding about the topic. The conceptualization includes the parties involved and how they interact over time, the ways in which these interactions occur and in which type of flow, and ultimately the positioning of the parties and interactions at specific interfaces. The development of the first contribution is supported by previous literature, exploratory research indicating the need for a framework to manage construction supply chains, and empirical research carried out in case studies.

Another contribution of this study is the set of best practices proposed. The set of practices was designed to be analysed, adapted, and adopted in different contexts by practitioners. The practices use the conceptual view of ETO construction supply chains as a background, so that they can be precisely located at specific interfaces and flows.

Such location is justified by the occurrence of problems at the interfaces of construction supply chains, and the practices were designed to act as a means to tackle them over time. The development of the second contribution is supported by previous literature and by the selection, extraction, cross-analysis, and consolidation of practices found in empirical research carried out in case studies.

From a practical viewpoint, the combination of the conceptual view of construction supply chains and the best practices proposed will probably be helpful to change the current business model of construction companies. Currently, it is very common that construction companies manage their supply chains from the perspective of each project, which increases fragmentation and does not tackle supply chain issues in an appropriate way. The proposition of this research is that construction companies manage their supply chains as production systems. The conceptual view and the practices proposed are focused on the design and improvement of such systems over time.

8.3 Limitations

This research proposes a framework for designing and improving ETO construction supply chains in the infrastructure sector, and such a framework is presented from the viewpoint of a construction company. In addition, the framework is divided into two parts, namely (i) a conceptualization of construction supply chains, and (ii) a set of practices. Limitations regarding this research are presented as follows.

The research focuses on companies building projects in the heavy infrastructure sector. This choice is based on the idea that those projects are highly complex and unique. It was assumed that companies building such projects have an Engineer-to-Order production strategy, which should be extended to the way they manage their supply chains. Housing, commercial, and other segments in the construction industry were not investigated.

Logistics activities performed at construction sites such as materials handling, layout optimization, among others, are not investigated. The study is directed to tactical and strategic levels, including the interfaces between the construction companies, their multiple projects, and their suppliers.

The supply chain in a construction company can easily reach more than 5.000 companies, which constitutes a wide network to be managed. Although this research approaches tier-2 suppliers and clients of contractors, the study focuses on tier-1 suppliers due to the availability of access to their information and the time limitation for completing this study.

The three generic actions defined by Koskela (2000) for managing production systems are design, operation and control, and improvement. Such actions are seen in an analogous manner in construction supply chain management. In its intrinsic proposition, the present research focuses on the design and improvement aspects of supply chains in the construction industry. Operation and control aspects are not directly included in the scope of this study.

This research comprises multiple case studies in companies building infrastructure projects. The choice of the companies is based on their size, revenue, complexity, nature of activities, and availability. However, it is worth mentioning that the companies investigated present characteristics that can be found across other companies in the heavy construction sector.

Although companies in Brazil and in the UK are investigated in this research, the study does not provide a wide comparison between the construction industries in both countries. However, findings from case studies are compared in order to highlight business-related cultural differences. The proposition of the present framework is not designated exclusively for companies in Brazil and in the UK.

Bresnen and Marshall (1998) conducted nine case studies in medium to large-scale construction projects. The authors found that partnering is a consequence of strategic decisions and choices, which may or may not be based on the economic context. Bresnen and Marshall (1999) investigated client-contractor collaboration and found that clients foster collaboration to increase control over the construction process. The authors indicate that trust is critical to enhance collaborative arrangements. In this research, out of the eight practices proposed, Supply Chain Governance has strong connections with the ideas presented above. However, the viewpoint in which a client is able to use its market position to encourage contractors to comply with its practices (Bresnen and Marshall 1999) was not the viewpoint explored in this research. Company C, a leading public organization in the UK construction sector, was studied as a client that fosters overall industry development.

The practices developed in this research are intrinsically related to either contract-led and/or contractor-led supply chain developments. In addition, the conceptual view of construction supply chains comprises the interface between the contractor and the client. Although findings of this research indicate that client-led and contractor-led supply chain initiatives coexist, the specifics of these two theoretical views were not explored. Client-led developments have a typical impact on contractors, especially when the client is a high-profile public organization. Briscoe *et al.* (2004) affirm that there is a need for better client leadership, which influences performance improvement and innovation across a supply chain. For example, Company C plays a strategic role in the construction industry in the UK, and steer the development of contractors by promoting improvement programs and spreading technological developments. Contractor-led initiatives have a direct impact on tier-1 suppliers and eventually affect other tiers of the supply chain. Bresnen (1996) corroborates this idea by affirming that internal organizational efforts produce effects in the structure and conduct of inter-organizational relations. These efforts have a more practical approach, especially when a contractor fosters the development of critical suppliers in specific operational aspects: productivity, time-compression, and reduction of non-conformances, among others.

8.4 Recommendations for Future Research

This research has investigated the topic of supply chain management in the heavy construction sector. Particularly, the topic of ETO supply chain structures is related to recent research developments. Therefore, there is a significant number of research opportunities to be explored, including the following:

- The interface between the Enterprise Level and the Owner justify further investigations. It is suggested the identification of recurrent problems at the interface, the definition of what types of flows represent the interactions between the parties, and the proposition of practices to be adopted to tackle such problems;

- The external factors (i.e. changes in the markets, contractual agreements, among others) affecting ETO construction supply chains should be enumerated and categorized;
- Further empirical studies, exploring how client-led and contractor-led initiatives influence the practices proposed in this research, are suggested as future research. Moreover, the study concerning how the financial power of clients influence the adoption of supply chain practices is suggested;
- Additional studies in ETO construction supply chains are recommended in order to create and validate a catalogue of problems and solutions in these supply structures. Such a catalogue might be used as a reference to create cross-sector improvement initiatives to tackle problems in a systemic way over time;
- The proposition of an assessment tool based on the practices devised in this research justifies further investigation. It is suggested that such a tool be used to evaluate the level of adherence of construction companies to the practices proposed to manage ETO construction supply chains. The scores regarding the level of adherence might be used to evaluate contractors in a long-term perspective and to establish benchmarks in a particular sector;
- The adaptation and implementation of the framework in a different ETO supply chain structure, such as those in the shipbuilding sector, should be further analysed. What are the adaptations required in the conceptualization and to what extent the proposed practices can be useful in a different context are key questions to be addressed.

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APPENDIX A – INTERVIEW PROTOCOL

Initial list of questions in Exploratory Interviews:

a) In your view, what is supply chain management?
b) In your opinion, currently what is the most relevant issue regarding supply chain management?
c) What do you consider the most urgent issues to be addressed in supply chain design and improvement?
d) What are the strategies that you consider effective in supply chain design?
e) What are the strategies that you consider effective in supply chain improvement?
f) Why is it so difficult to achieve supply chain integration?
g) What elements do you consider essential in a framework to manage supply chains?
h) Is context important in supply chain management?
i) Is a contextualized framework to manage construction supply chains necessary?

APPENDIX B – LOG OF ACTIVITIES

The log of activities in Case Study 1 (Part 2) is presented below:

Item	Date	People	Activity
1	13 November 2013	Procurement Manager and Procurement Associate	Opening Meeting
2	14 November 2013	Procurement Associate	Definition of practices to be assessed
3	19 November 2013	Procurement Associate and Senior Costs Associate	Assessment of practices, and collection of documents
4	20 November 2013	Procurement Associate and Senior Quality Associate	Assessment of practices, and collection of documents
5	21 November 2013	Procurement Associate	Assessment of practices, and collection of documents
6	26 November 2013	Procurement Associate	Assessment of practices, and collection of documents
7	28 November 2013	Procurement Manager and Procurement Associate	Assessment of practices, and collection of documents
8	3 December 2013	Procurement Associate	Assessment of practices, and collection of documents
9	5 December 2013	Procurement Associate	Assessment of practices, and collection of documents
10	10 December 2013	Procurement Manager and Procurement Associate	Assessment of practices, and collection of documents
11	12 December 2013	Procurement Associate and Senior Quality Associate	Assessment of practices, and collection of documents
12	19 December 2013	Procurement Manager and Procurement Associate	Data Validation Meeting

APPENDIX C – LOG OF ACTIVITIES

The log of activities in Case Study 2 is presented below:

Item	Date	People	Activity
1	16 April 2014	Proj. Manager, Snr. Quantity Surveyor, Quantity Surveyor, Commerc. Manager	Opening Meeting
2	16 April 2014	Commercial Manager, Snr. Quantity Surveyor	Overview of the company and definition of practices to be assessed
3	28 May 2014	Snr. Quantity Surveyor	Interview, assessment of practices, and collection of documents
4	10 June 2014	Supply Chain Manager – Subcontractors	Interview, assessment of practices, and collection of documents
5	03 July 2014	Supply Chain Manager	Interview, assessment of practices, and collection of documents
6	16 July 2014	Commercial Director	Interview, assessment of practices, and collection of documents
7	04 August 2014	Supply Chain Manager – Materials	Interview, assessment of practices, and collection of documents
8	18 August 2014	Highways Sector Performance Manager, Quality and Performance Manager	Data Validation Meeting

APPENDIX D – LOG OF ACTIVITIES

The log of activities in Case Study 3 is presented below:

Item	Date	People	Activity
1	18 September 2013	Company C employee, Representatives of 3 suppliers	Opening Meeting
2	23 October 2013	Company C employee, Representatives of 3 suppliers	Overview of the company and definition of practices to be assessed
3	6 November 2013	Company C employee, Representatives of 3 suppliers	Assessment of practices, and collection of documents
4	23 January 2014	Company C employee, Representatives of 3 suppliers	Internal Workshop
5	3 March 2014	Company C employee, Representatives of 3 suppliers	Assessment of practices, and collection of documents
6	4 March 2014	Company C employee, Representatives of 3 suppliers	Assessment of practices, and collection of documents
7	11 March 2014	Company C employees (3)	Interview, assessment of practices, and collection of documents
8	11 March 2014	Company C employees (3)	Interview, assessment of practices, and collection of documents
9	2 May 2014	Company C employees (2)	Interview, assessment of practices, and collection of documents
10	2 May 2014	Company C employee	Interview, assessment of practices, and collection of documents
11	7 July 2014	Company C employees (3), Representatives of 4 suppliers	Observation of Meeting
12	14 March 2014	Company C employees	Data Validation (NDD)
13	14 May 2014	Company C employees	Data Validation (MP)

APPENDIX E – CASE STUDY PROTOCOL

Protocol adopted in Case Study 1 (Part 2), Case Study 2, and Case Study 3:

Item	Activities	Comments
Research Proposal	Prepare and submit a research proposal containing the activities to be developed, overview of the schedule, and what information should be available	Research Proposal 1,Research Proposal 2,Research Proposal 3
Contact	Define the key points of contact in each case	List of contacts 1,List of contacts 2, List of contacts 3
Data Collection	Organize interview protocols, create folders to collect and archive documents, and create a log of meetings	Data Archive 1, Data Archive 2, Data Archive 3
General Schedule	Prepare a detailed schedule for each case study	Schedule 1, Schedule 2, Schedule 3
Sequence	Opening Meeting General interviews to understand what practices will be assessed in the cases Definition of a list of activities and people necessary to collect specific information Review and validate information collected	General Plan 1, General Plan 2, General Plan 3
Analysis	Analyse data collected	Summary of interviews, summary of documents, summary of additional information required
Outputs	Write Case Study Reports and carry out a Cross-case analysis	Case Study 1 (Part 2) Report, Case Study 2 Report, Case Study 3 Report